A STUDY OF THE ACIDITY OF THREE DARTMOUTH, NOVA SCOTIA LAKES 1: THE pH OF PRECIPITATION FALLING ON MICMAC LAKE.

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1: THE pH OF PRECIPITATION FALLING ON MICMAC LAKE

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PREFACE

There is no reason to doubt either the reality or seriousness of acid rain. Acidic precipitation has been recorded in many parts of the world, including northeastern United States (Cogbill 1976; Raynor and Hayes 1981) and eastern Canada (Sergeant et al. 1981; Underwood 1981). Such precipitation may acidify soils and the water in lakes and streams, leach important nutrients from plant foliage and soil, and introduce toxic levels of other minerals from the soil into the water. Ample data have been collected to show that in seriously affected areas, lakes and rivers that once supported large natural fish populations are now without fish and for all practical purposes these waters are biologically dead; in the more extreme cases plants in such areas have been killed or stunted (Braekke 1976; Toribara et al. 1979). The most obvious example in Canada has occurred in the Sudbury-Timmins area of Ontario where the large smelters are operating (Beamish 1976; Summers and Whelpdale 1976). Similar serious atmospheric pollution has occurred in other areas where large coal- or oil-fired power plants are located (Lewis 1978).

Although acid rain is real and very serious in some parts of Canada, scientists are not yet certain about how far from their point of origin the acids are carried in the atmosphere and, more particularly, to what extent they affect plant and animal life in more remote areas. Large portions of Canada are far away from the huge industrial centres. Does the atmospheric pollution originating in Ontario, Quebec and the central and eastern United States have a significant effect on fish and other aquatic life in the Maritime Provinces? Is there acidic precipitation resulting from our own local burning of fossil fuels? Government agencies and scientists are presently engaged with these questions but it may take years to provide sufficient data to support anything more than intelligent guesses regarding the source and seriousness of acid rain in Nova Scotia. In the meantime, anxious and puzzled government administrators cannot take chances; they must plan for the worst and hope for the best.

The answer to the question of whether rains are seriously affecting the acidity of a lake or river appears to be amazingly simple. All that is needed is to periodically measure the acidity of the water and then decide whether or not it is reaching dangerous levels.

It is not uncommon, however, in dealing with environmental problems to find that what at first appears to be relatively simple is actually much more complex. The acidity of the rain is not the only factor that can alter the pH of our lakes and rivers. It is also affected by the types of rocks and soils that come in contact with the water, as well as a number of different biochemical processes associated with the growth and decay of both microscopic and macroscopic plant life. When the lakes being investigated are relatively remote from major centers of atmospheric pollution, these other factors become increasingly important. Part of the problem is to distinguish between the acidity in a lake that is caused by acid rain and the acidity caused by other environmental and biological factors.

It is with this as a background that the present study of the acidity in some of the Dartmouth lakes has been carried out. Initially it was intended to include all the 22 lakes within the city limits, but it was soon found that in order to answer all the necessary questions, the number of lakes to be studied would have to be greatly reduced. It was finally decided to confine this investigation to one chain of three lakes, Lake Charles, Micmac Lake and Banook Lake, and their associated drainage areas (Fig. 1).

It is fully realized that these studies have been confined to a very small area of Nova Scotia, and they may not be typical of what is occuring in other parts of the province. However, it was thought that an extensive and detailed study of one small area may contribute basic information that will be useful to those who are in a position to examine the effects of acid rain on lakes and rivers in a much larger area.

The location of those Dartmouth lakes has one particular advantage in the study of acid rain: it is within 4 km of a major power plant, at Tuft's Cove, and within 20 km of most of the air pollution contributed by the cities of Dartmouth and Halifax (Fig. 1).

This paper is the first part of a larger study dealing with the pH values of these three particular Dartmouth lakes. It is mainly concerned with the acidity of the precipitation falling in the area of the lakes. Subsequent papers will record various diurnal and seasonal patterns that were observed in the pH values of the lake waters over a period of several years. An attempt will be made to point out some of the principal biological and environmental factors that are responsible for these changes in pH. In addition, it will be shown that certain human activities in this area can also significantly affect the pH of the water.

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ABSTRACT

Castell, C.H., I. Novaczek and J.D. Castell. 1982. A study of the acidity of three Dartmouth, Nova Scotia, lakes 1: The pH of precipitation falling on Micmac Lake. Can. Tech. Rep. Fish. Aquat. Sci. 1231, xi + 35 p.

In order to determine the acidity of rainfall at Micmac Lake, adjacent to the metropolitan area of Halifax-Dartmouth, a sampling program has been carried out from 1 January 1980 to 31 December 1981. The pH of approximately 97% by volume of the precipitation over this time period has been determined. One third of the precipitation events had a pH of less than 4.3 and only 14% had a pH of over 5.0. The average pH value was 4.4. The pH of the precipitation was influenced primarily by the wind direction at the time of the rain or snowfall. Precipitation brought by south and southwest winds was much more acidic than that brought by north and east winds. Because of a seasonal fluctuation in prevailing wind direction, there was a seasonal variation in the pH of the precipitation. The acidity was also influenced by whether the sample was in the form of rain or snow, by the speed of the wind, and by the accumulated volume, but not by the time of day of the precipitation. Mixtures of rain or melted snow with lake water indicated that relatively massive volumes of precipitation are required to change the pH of lake water to a biologically significant degree.

Key words: precipitation, pH, acid rain.

RÉSUMÉ

Castell, C.H., I. Novaczek and J.D. Castell. 1982. A study of the acidity of three Dartmouth, Nova Scotia, lakes 1: The pH of precipitation falling on Micmac Lake. Can. Tech. Rep. Fish. Aquat. Sci. 1231, xi + 35 p.

Pour déterminer l'acidité de la pluie au Micmac Lac, près d'Halifax-Dartmouth, un programme d'échantillonnage a été exécuté du 1 Janvier 1980 au 31 Decembre 1981. Le pH d'approximativment 97% du volume de la précipitation tombée pendant cette période été determiné. Un tiers des précipitations avait un pH inférieur a 4.3; seulement 14% avait un pH plus haut que 5.0. Le pH moyen était de 4.4. Le pH de la précipitation a été influencé premiérement par la direction du vent pendant la période de pluie ou de neige. Les précipitations portées par les vents du sud et du sudouest étaient plus acides que celles portées par les vents du nord et de l'est. Une fluctuation saisonniére des vents dominants a cousé une fluctuation saisonniére du pH des précipitations. L'acidité des échantillons de précipitation a aussi été influencée par le fait que les échantillons étaient constitués de pluie ou de neige, par le vitesse de vent et par le volume total de la précipitation, mais non pas par le moment de la précipitation a l'intérieur de la journée. Les mélanges de la pluie et de la neige avec l'eau du lac ont indiqué que des volumes relativements importants de précipitation sont requis pour changer le pH du lac a un degré biologiquement significatif.

INTRODUCTION

In this report, the following questions have been asked dealing with the precipitation falling next to Micmac Lake during the period 1 January 1980 to 31 December 1981. What was the range of the pH values of rain and snow? What proportion of the precipitation in this area could be considered biologically harmful? Is there any seasonal pattern in the pH values of precipitation? Is there a correlation between the direction and speed of the wind at the time of the precipitation and the pH of the rain or snow? Are there changes in the pH of rain or snow during one storm and, if so, are these related to changes in wind direction? Does the time of day or volume of the precipitation affect the pH? Finally, by measuring the pH of different mixtures of rain or snow and lake water, can we determine the amount of precipitation which must be added to a lake to bring about a biologically significant lowering of its pH?

MATERIALS AND METHODS

Samples of freshly fallen rain and snow were collected in a rectangular plastic tray that was 26 cm by 21 cm and 14 cm deep. The collector was positioned on a small rise, unobstructed by tree cover, 1 metre from the ground, on the northeast shore of Micmac Lake (Fig. 1). Volume of rain in the container was measured immediately after termination of the precipitation. A portion was transferred to plastic cups with lids that were kept on until the electrodes were about to be inserted for pH determination. In most cases determinations were carried out within 15 to 20 minutes after the samples had been collected. During most of the year the problem of differences of water temperature in measuring pH was overcome by the use of a temperature compensator on the meter. Where snow or ice were involved, samples in a closed plastic container were left in warm, but not hot, water until they had melted and the temperature had risen to 20°C, at which time the pH was immediately determined. The pH meter used was a Model 76, expanded-scale Beckman, calibrated with a standard buffer solution at pH 7.

Between 1 January 1980 and 31 December 1981, 463 samples were collected. From 17 January 1981, the volume in millilitres of each sample was also recorded and converted to millimetres of rainfall. At the time of collection and during a rain- or snowfall, the wind direction was noted.

Practical experience soon shows that there are some difficulties in trying to determine wind direction at the time of precipitation. It is fairly simple to distinguish northerly, southerly, easterly and westerly winds. It is not always easy to distinguish between wind directions from two closely related points of the compass (i.e., NNE from NE or SSW from S). Wind direction is not always constant and may be changing during the rain- or snowfall. In addition, it is very obvious that sometimes wind direction at lake level may differ from that in the upper atmosphere, as seen by the direction of cloud movement, or smoke from tall smoke stacks at the power station in Bedford Basin (Fig. 1). There were also times, especially during the night, when the winds blew unobserved.

"Lake-level" wind direction was determined through the use of a wind vane, and by observations of wave direction on Micmac Lake, and the direction of smoke from neighborhood chimneys. In spite of the difficulties, every effort was made to ensure the observations were as accurate as possible. These observations have been checked with data from monthly meteorological summaries from Environment Canada for Shearwater "A", which is approximately 7.5 km southeast of the collection site on Micmac Lake. Usually, but not always, directions recorded for Micmac Lake were the same as those of Shearwater "A". When they did not agree, the differences were relatively insignificant. In those few instances where Micmac Lake records were incomplete, those of Shearwater "A" were used for the preparation of tables and figures.

The samples taken included precipitation falling on 257 out of a total of 339 days having precipitation in 1980-81. The events sampled accounted for roughly 97% of the total volume of rainfall, as judged from records of the Environment Canada monitoring station at Shearwater "A".

The Shearwater "A" records were used to determine wind speed during the precipitations sampled. Because there are variations between weather records of Micmac Lake and Shearwater "A", these wind speeds are only approximations. The strength of the wind is seldom constant throughout a rain- or snowfall and may vary from almost dead calm to very strong gales. The samples were therefore designated as falling into three categories: when the wind was predominantely less than 5 km h^{-1}; 5-45 km h^{-1}; or in excess of 45 km h^{-1}.

For the purpose of analysis, the data were divided into precipitation events (App. A). An event is any sample or closely spaced series of samples of either rain- or snowfall for which wind direction was constant. When wind direction changed during the rain or snowfall, it was considered to be made up of more than one event. When pH varied from one sample to another within an event, an overall average or, if possible, volume-adjusted pH was determined. Three hundred and sixty-three events were recorded. The overall pH for a group of events has been expressed in two ways. Average pH value is simply the sum of pH values divided by the number of events. This is not equivalent to the average hydrogen ion activity expressed as a pH value. Where volumes were recorded (1981 samples), the volume-adjusted pH (VApH) has also been calculated. This is what the overall pH would be if all the samples were combined.

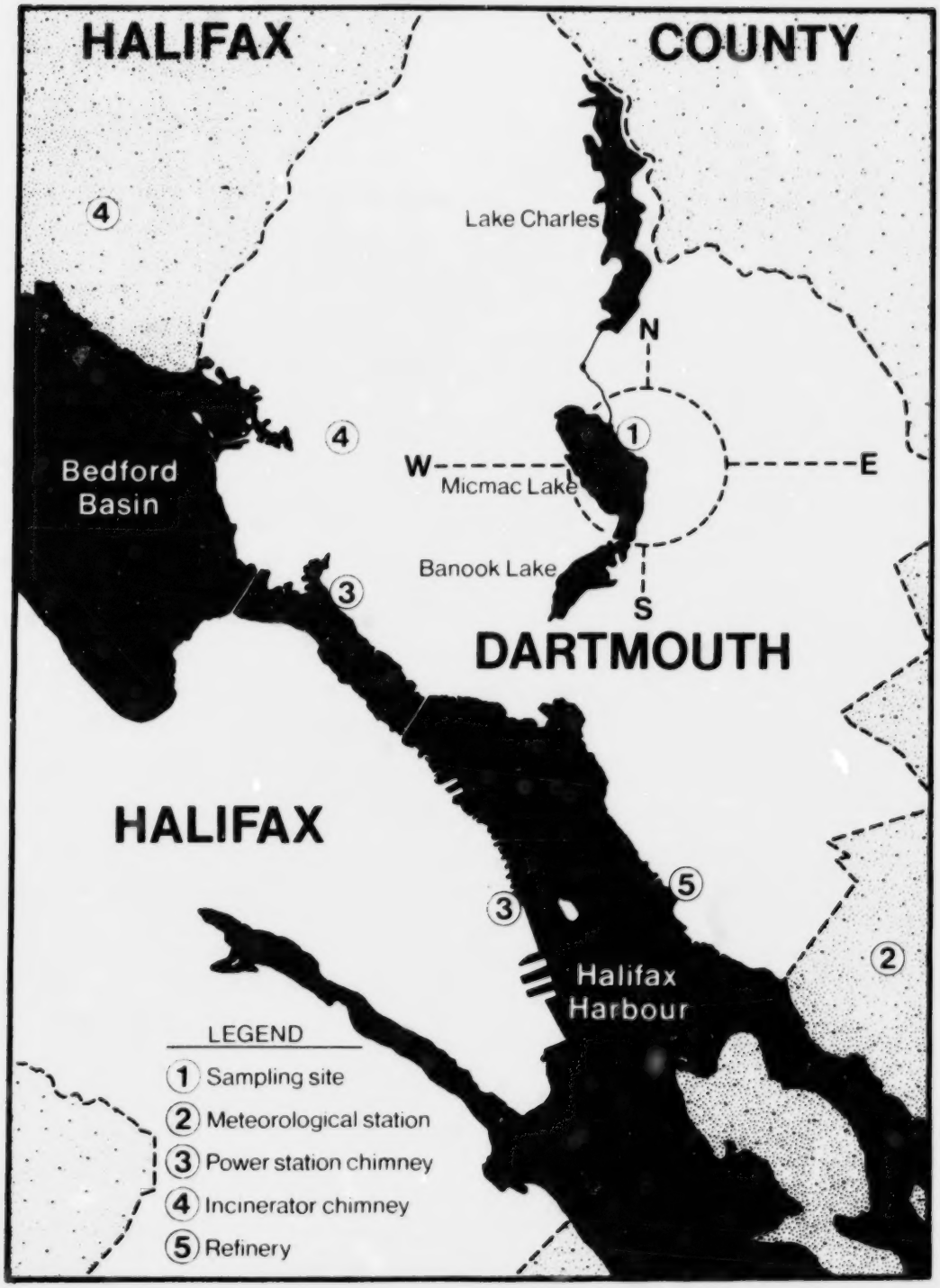

FIG 1. Map of Halifax-Dartmouth, showing the sampling site and major sources of air pollution.

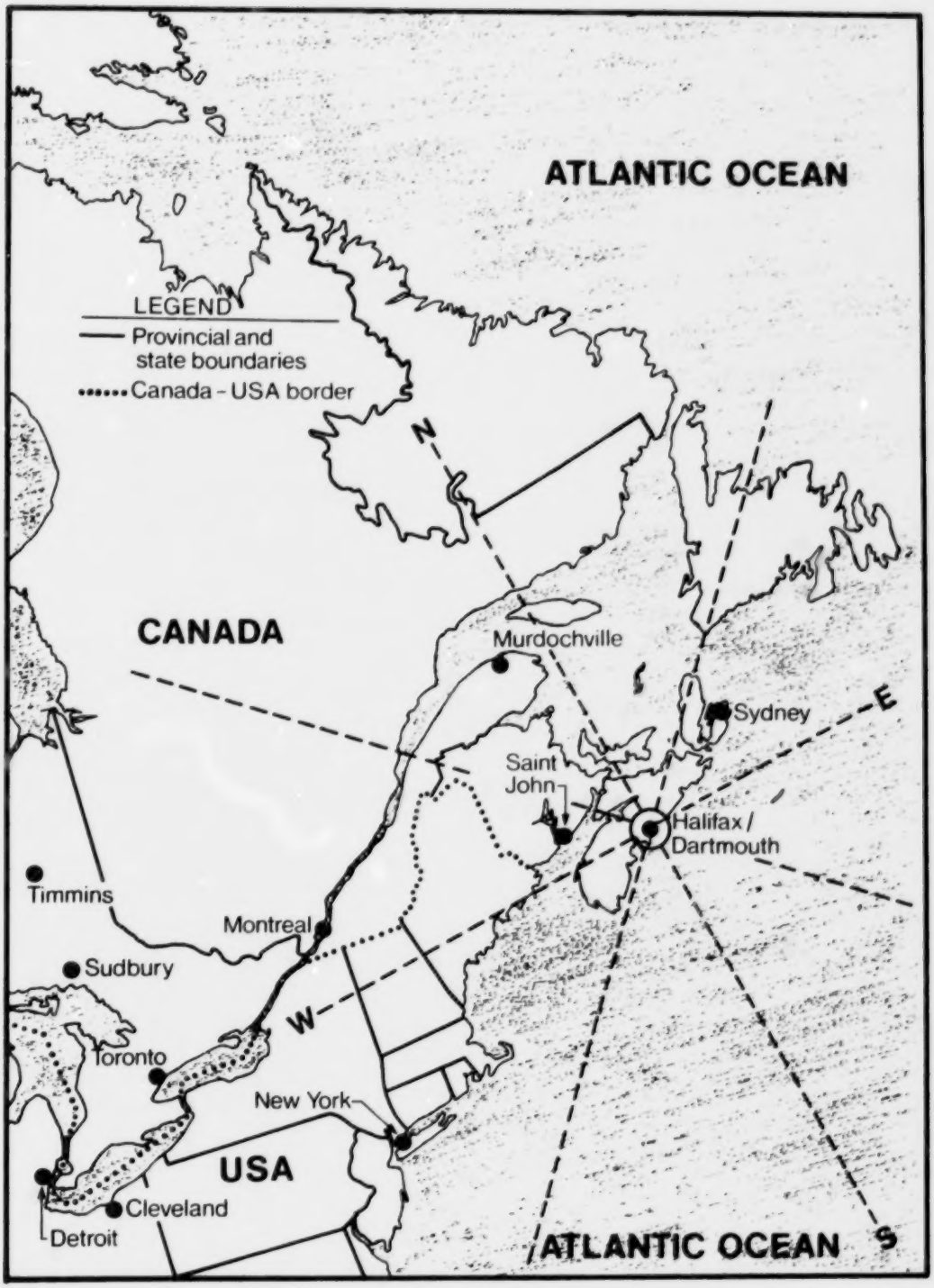

FIG 2. Map of eastern North America, showing the location of Halifax-Dartmouth with respect to distant centres with extreme air pollution.

The formulae for the calculation of these figures are as follows:

$$\text{Average pH value} = \frac{\Sigma_i \, pH_i}{n}$$

$$\text{Volume adjusted pH} = -\log_{10}\left[\frac{\Sigma_i \, ([H^+]_i \times V_i)}{\Sigma_i \, V_i}\right]$$

Where pH_i = the pH of the i^{th} precipitation event,

n = the number of precipitation events

$[H^+]_i$ = the hydrogen ion activity of the i^{th} precipitation sample and

V_i = the volume of the i^{th} precipitation sample.

RESULTS

RANGE AND SEASONAL DISTRIBUTION OF pH VALUES

The precipitation events sampled in each month have been described and the trends illustrated (Fig. 3). Two things are apparent from these data. Firstly, there was a wide range of pHs, from 3.3 to 6.1; and, secondly, there was a seasonal variation which was similar in both years. Values tended to be higher in the winter and early spring and lower during summer. The average pH value for all events was 4.4 and the VApH for 1981 was 4.3. For purposes of comparison, the pH values were divided into four ranges:

1 - under pH 4.0
2 - pH 4.0-4.25
3 - pH 4.3-4.95
4 - pH 5 or more

During the two-year period, 52% of events were of pH 4.3-4.95 and a further 18% were in the range 4.0-4.25. Only 14% had a pH of 5.0 or more, while 16% were extremely acidic with pH less than 4.0. The percentages of events in each pH range for each season and overall are illustrated (Fig. 4). In summer, the precipitation was predominantely of pH less than 4.25, with 28% being less than pH 4.0 and none being over pH 5.0. By contrast, precipitation in the spring and autumn was most commonly of pH 4.3-4.95, while, in winter, 29% of events were of pH over 5.0.

Industrial production of acid wastes occurs year round, but the discharge from private fuel burning might reasonably be expected to increase in winter, leading one to expect more acid rain at this time. This is clearly not the case, and the reason will become evident when wind direction is considered.

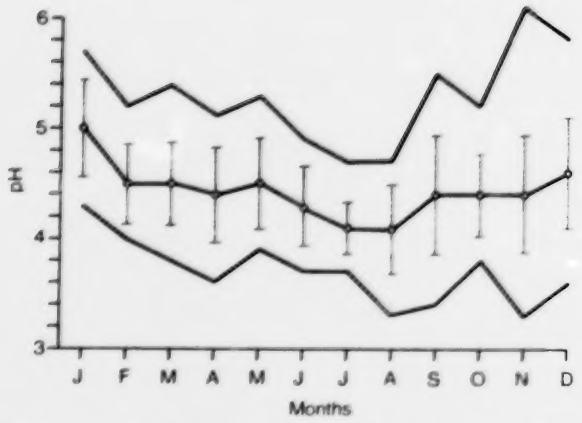

FIG. 3. The average, maximum and minimum pH values for precipitation in each month, for 1980-81, at Micmac Lake. (One standard deviation around the mean is shown as a vertical line.)

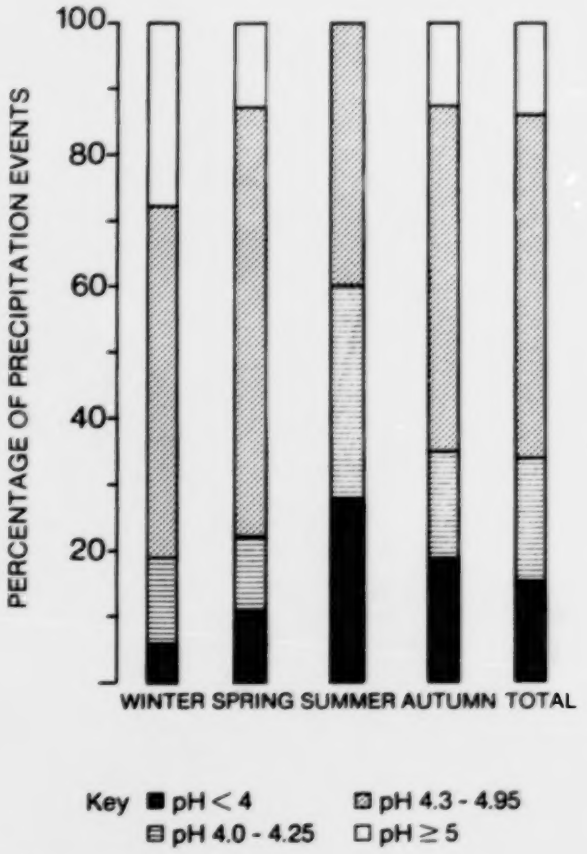

FIG. 4. Distribution of precipitation events in each pH range for each season of the year at Micmac Lake in 1980-81.

WIND DIRECTION AND THE pH OF RAIN AND SNOW

Average pH values for precipitation events from each of 16 points of the compass and the percentage of the total number of events from each of these wind directions are illustrated (Fig. 5). Detailed data are tabulated in Appendix Table D-1. At a glance one can see the relation between wind direction and pH of the precipitation. Values are highest for northeast winds and gradually decrease as one moves away from this point on the compass - either clockwise or counterclockwise. The lowest pH values occur when the winds are from the southwest.

The data can be grouped into sectors, each sector being composed of four compass points. The largest proportion (32%) of the sampled events came from the SW sector. In 1981 these events contributed 35% of the total volume of rain collected. Slightly fewer events (28%) came from the SE (34% of the 1981 volume). Only 21% of events, but 24% of the 1981 volume, came from the NE. A further 18% of events, but only 7% of the 1981 volume, came from NW. In short, the most frequent winds during precipitation were also those bringing the greatest volume of rain and having the greatest acid content.

The correlation between pH and wind direction greatly influences the seasonal trend in pH, because wind direction is itself seasonally variable (Table 1). In summer, when the average pH is lowest, winds are predominantly from the south. In winter, when precipitation is less acid, the prevailing wind is from the northwest. The interactions of season, wind sector and pH range are summarized (Fig. 6). More detailed data are tabulated in Appendix Tables D-2 and D-3. It is clear that the seasonal change in wind direction is accompanied by a change in pH values of precipitation. There does also appear, however, to be a seasonal difference in pH values for winds within each sector. In other words, seasonal variation in pH can be accounted for mainly by seasonal variation in wind direction, but other factors are involved.

An analysis of variance of pH by season and wind direction (Appendix B) shows that in statistical terms some differences among the averages for each wind sector are highly significant ($p = 0.001$), but that there are no significant differences among the seasons. The multiple classification analysis reveals that the differences in pH which seem to be due to season disappear when the means are adjusted to take other variables into account; in other words, season and wind direction are not independent variables.

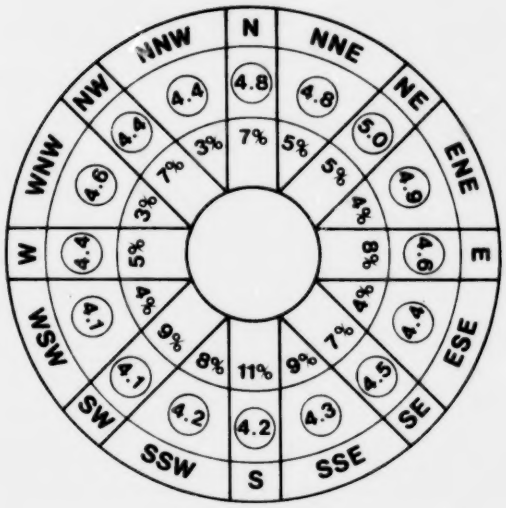

FIG. 5 Relation between pH values of rain and snow and wind direction at the time of precipitation, 1980-81. (The proportion of events from each direction is shown in the inner ring. Average pH values are circled. One percent of events were of unknown wind direction.)

TABLE 1. Average pH of precipitation at Micmac Lake and prevailing wind directin at Shearwater "A" meteorological station for each month of 1980.

Month	Prevailing wind	Average pH value
January	WNW	4.8
February	WNW	4.8
March	N	4.6
April	N	4.5
May	S	4.2
June	S	4.3
July	S	4.0
August	S	4.1
September	S	4.1
October	W	4.4
November	NW	4.5
December	NW	4.4

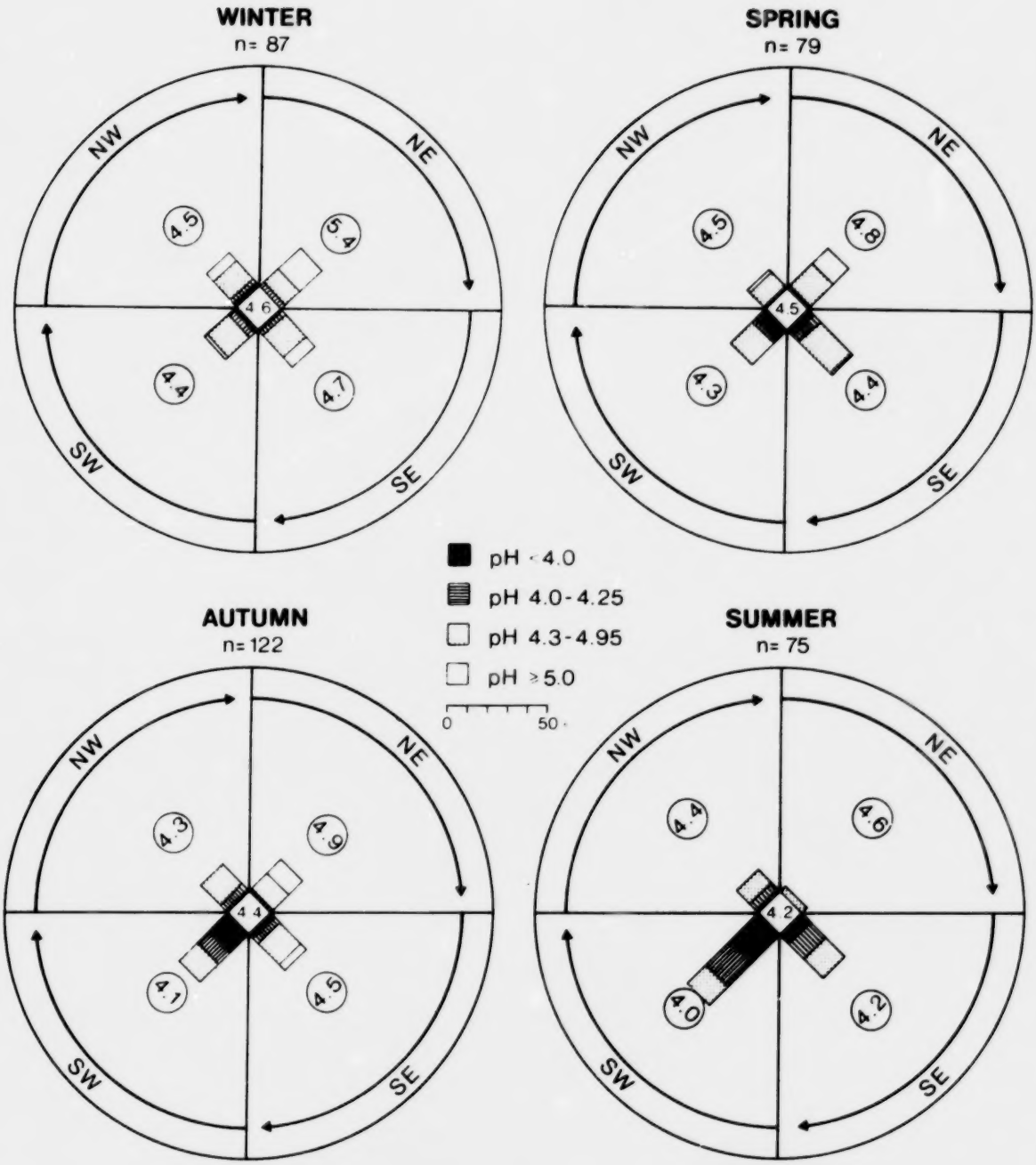

Fig. 6 Seasonal variation in wind direction during precipitation and pH of precipitation. (For each season, % frequency of events from each wind sector is shown by the length of the bar. The % frequency of events in each pH range is indicated by pattern. Average pH value for each sector is circled. Overall pH for each season is shown in the central square.)

CHANGES IN THE pH OF PRECIPITATION DURING THE PROGRESS OF A STORM

There were two principal reasons for the observations recorded in this section. The first was to see whether there are changes in the pH of rain or snow during the progress of a storm. The second reason was to determine whether changes in the pH of precipitation are accompanied by changes in the wind direction.

To do this, samples were collected at two or more intervals during the course of a continuous storm or a series of short associated showers and their pH values were recorded. At the same time a record was kept of wind direction at the time of sampling (Appendix C).

The answer to the first question soon became evident: pH of rain or snow frequently did change as the storm progressed. Sometimes the values gradually increased and sometimes they decreased. Occasionally pH levels remained constant during rains that lasted up to 8 hours or more.

A summary of changes noted within rain- and snowfalls (Table 2) shows that, on 66 occasions, consecutive samples were taken while the wind remained blowing from the same sector. In 52% of these cases, regardless of wind direction, pH value of the precipitation gradually increased. In 23%, pH remained constant. In 26% of the cases, pH decreased. The pH changes ranged up to 0.7 pH units, but in 85% of the cases the change was 0.4 pH units or less.

One example of consecutive samples of rain from the same general wind direction comes from the data of 15 November 1981 (Fig. 7). The wind blew from the east all day long and most of the following night. As might be expected with wind from this direction, pH of the rain was relatively high and remained so throughout the day.

In 123 cases, consecutive samples were taken during rain- and snowfalls when the wind direction varied from one sample to the next. To find a consistent relationship between changes in wind direction during precipitation and changes in pH of the precipitation proved difficult. In some cases, when rain continued for 8 or 10 hours or more, the relationship was quite clear. In other cases, the relation between wind and pH was not so apparent. For example, on 17 January 1981 (Fig. 8) the wind was shifting between northeast and north and the pH continued to increase. However, just prior to the rainfall, the winds had been blowing from WNW and NW. This accounts for the lower initial pH values, followed by an increase as the winds shifted from west to north. In another case, an increase in pH occurred as the wind changed from NW to NE (Fig. 9).

A decrease in pH was noted as the winds shifted clockwise from east to southwest (Fig. 10). Other examples such as those shown were also encountered, but the relationships of pH and wind changes were not always consistent.

When the wind shifted, change in pH could be up to 1.1 pH units over the course of the precipitation, but it was only 0.4 units or less in 77% of the cases. Since such a change commonly occurs even when there is no change in wind direction, it is difficult to draw conclusions from these data. However, if the proportions of positive and negative pH changes during various shifts in wind direction are compared to the proportions occurring when the wind did not change (Table 2), a pattern does emerge which is consistent with the correlations between wind direction and precipitation pH, which have already been discussed.

There was a greater than expected proportion of positive changes in pH when the wind shifted clockwise from west to east via north or counter-clockwise from south to north via east. For shifts from south to north via west, the results were mixed because pH tended to decrease in a wind change from south to southwest. Considering wind changes from southwest to north via west, pH changes were predominantly positive. Similarly, when winds shifted from west to east via south, there were slightly more positive pH changes than in constant winds, but there was a greater proportion of positive changes for winds shifting from south to east.

TABLE 2. Comparison of changes in pH of precipitation which occurred when the wind remained blowing from the same sector with changes in pH which occurred when the wind varied. (pos - positive change; neg - negative change).

		% having each type of pH change		
Change in wind	n	0	pos	neg
No change	66	23	52	26
N to S via E	30	23	37	40
E to W via S	51	20	39	41
S to N via W	39	18	54	28
SW to N via W	24	17	71	13
W to E via N	15	20	67	13
N to S via W	6	17	50	33
E to W via N	21	14	53	33
S to N via E	26	4	69	27
W to E via S	17	6	59	35
S to E	9	0	67	33

When the wind shifted from east to west via north, the proportions of positive and negative pH changes were similar to those in the group of samples having a constant wind direction.

There were fewer positive and more negative pH changes than expected when wind shifted from north to south via east and from east to west via south. There were too few data for shifts of wind from north to south via west to ascertain any trend.

The variability encountered suggests that factors other than wind direction, such as periods of calm, strength and duration of winds and relative volume of precipitation during different periods of the rainstorm, need to be taken into consideration.

COMPARISON OF THE pH VALUES OF RAIN AND SNOW

During the months December through March 1980 and 1981, 112 events of rain- and snowfall were sampled and wind directions at the time of precipitation were recorded. There were 49 samples of snow and 63 samples of rain. The results

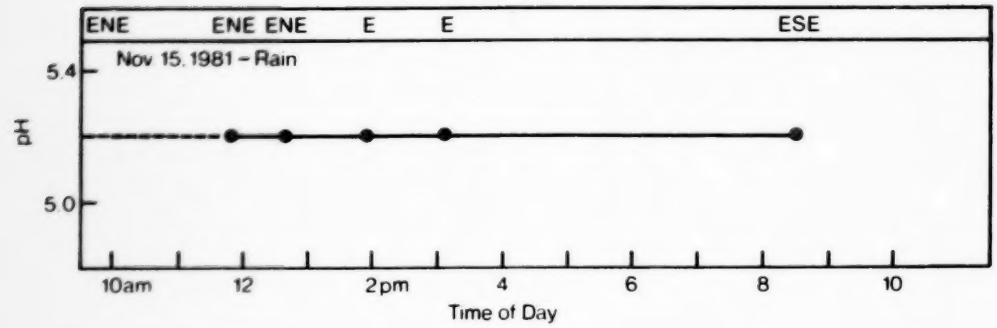

FIG. 7. Record of wind direction and pH for precipitation on 15 November 1981.

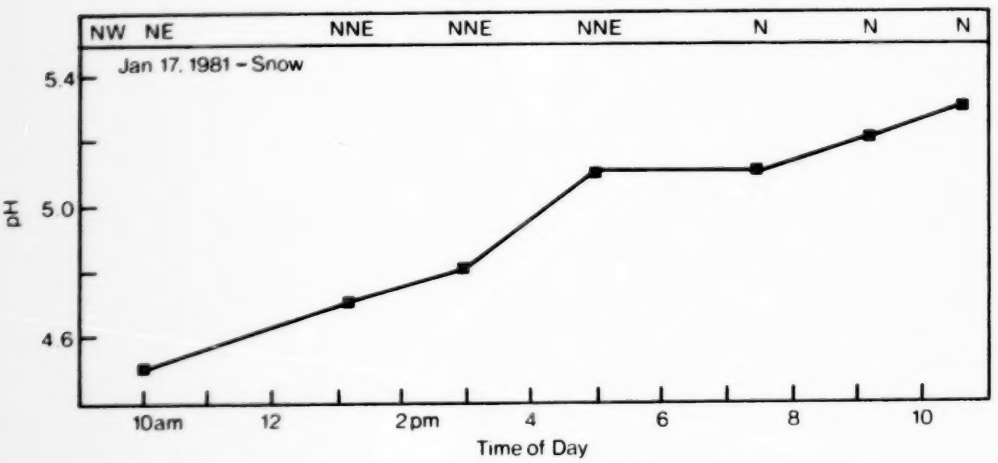

FIG. 8. Record of wind direction and pH for precipitation on 17 January 1981.

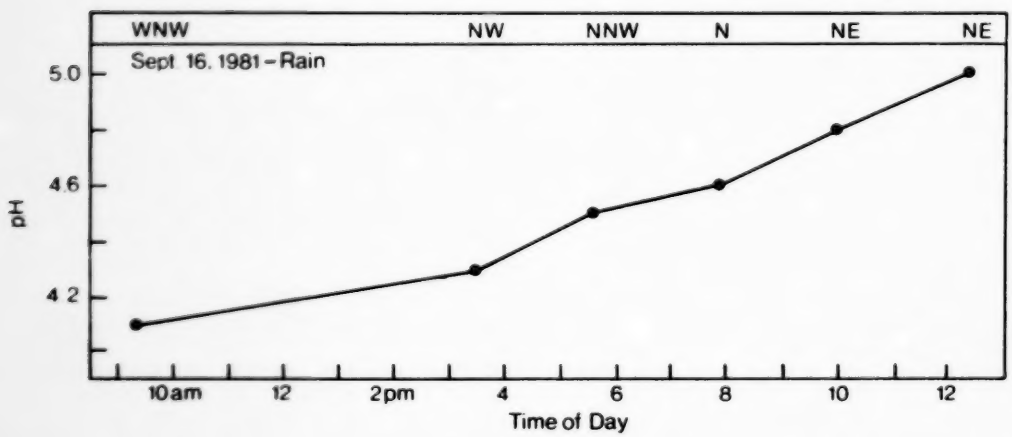

FIG. 9. Record of wind direction and pH for precipitation on 16 September 1981.

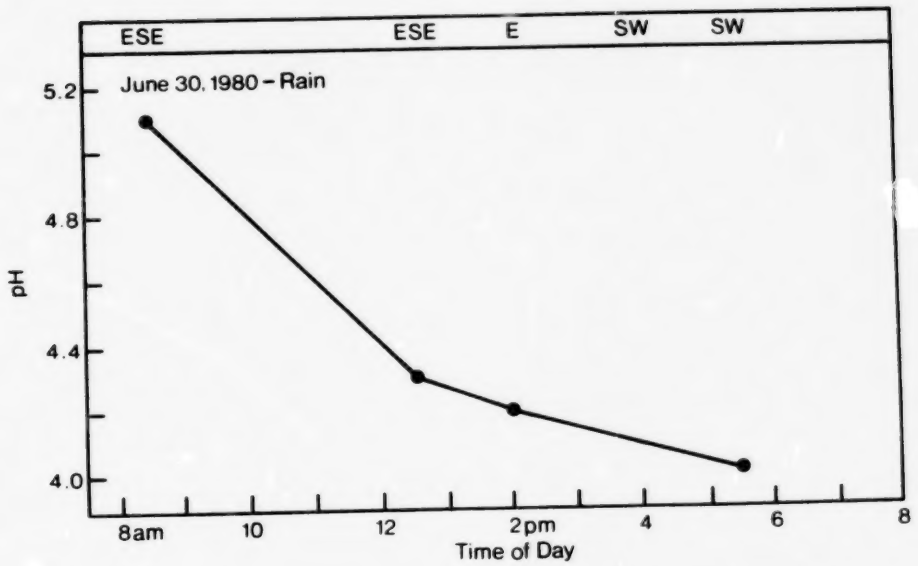

FIG. 10. Record of wind direction and pH for precipitation on 30 June 1980.

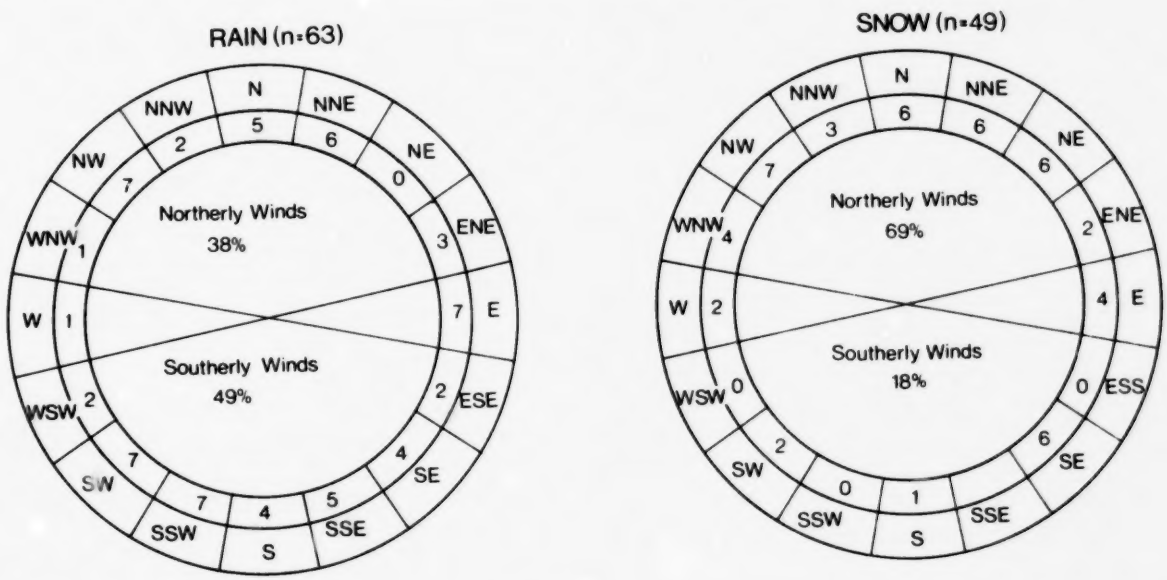

FIG. 11. The number of rainfalls and snowfalls accompanied by winds from each compass direction in December through March of 1980 and 1981.

(Table 3) indicate that pH values of snow were higher than those of rain. Analysis of variance (Appendix B) shows the difference between the two types of precipitation to be highly significant ($p = 0.001$).

Examination of wind directions at the times of precipitation suggests that wind direction is responsible for some of the difference in pH. During the winter period of 1980-81, 69% of the snowstorms occurred when winds were blowing from northerly directions and only 18% when winds were southerly (Fig. 11). In contrast to this, 49% of rains occurred when winds were blowing from southerly directions. It would appear that the same northerly winds that bring lower temperatures also are responsible for the atmosphere containing less acid pollution. The snow has higher pH values than the rain because it forms when there is less acid present in the atmosphere. However, this is not the whole story. Multiple classification analysis (Appendix B) reveals that even after the deviation of the pH of snow from the grand mean pH is adjusted for wind direction and other variables, there still remains a significant difference between the two types of precipitation.

The question arises as to whether there is some characteristic of the snow itself, or the formation of snow crystals in the atmosphere, that accounts for this higher pH value. It has been suggested that as the crystals form, some of the acids in the atmosphere tend to be excluded (Summers and Whelpdale 1976).

If one compares pH values of rain and snow coming from each wind sector (Table 3), it can be seen that even within one wind sector snow generally has a higher pH than rain. It would therefore seem that both possible reasons for the high pH of snow are correct. Snow is often less acid simply because it is brought by northerly winds, but also because of the exclusion of ions during its formation.

TABLE 3. Comparison of pH values of rain and snow which fell on Micmac Lake from 1 December through 31 March of 1980 and 1981.

	pH					
	Rain			Snow		
Wind sector	Avg	SD	n	Avg	SD	n
NE	4.7	0.45	14	5.0	0.50	20
SE	4.5	0.43	18	4.8	0.45	9
SW	4.4	0.36	20	4.3	0.18	5
NW	4.4	0.46	11	4.7	0.39	15
Overall	4.5	0.41	63	4.8	0.47	49

OTHER FACTORS RELATED TO THE pH OF PRECIPITATION

Although wind direction seems to be an important factor in determining the acidity of precipitation, variability in the data suggests that other factors are involved. Wind speed, amount of precipitation and time of day have been investigated.

The data for 1 January 1980 to 30 November 1981 were divided into three categories by wind speeds during precipitation (Table 4). The mean pH value for 58 events accompanied by gentle winds of up to 5 km h^{-1} was 4.1. This is more acidic than the overall average of 4.4. In 21 cases, the precipitation was accompanied by winds of over 45 km h^{-1}. Mean pH for these events was 4.8, which is much higher than the overall average. Analysis of variance reveals a highly significant difference between wind speed categories (Appendix B) with no significant interaction between speed and direction.

A second factor is the volume of precipitation. One might expect that if only a small amount of rain falls through an air mass with a certain component of acid, the acidity of the resulting concentrated solution would be greater than if a large volume of water washed the same air mass. Indeed, when precipitation events are divided into three depth ranges (using Shearwater "A" data for cases where the volume was not measured) it can be seen that samples from rainfalls of less than 2 mm accumulated depth at the time of sampling have an average pH of only 4.3, while samples from rainfalls of over 10 mm depth have an average pH of 4.6 (Table 4). Overall, there is a highly significant difference among the means of the volume ranges (Appendix B) and there is no significant interaction between volume of precipitation and wind direction.

For those events for which a time of day could be specified, the data were grouped into four ranges. For all times of day, average pH was the same as or within 0.1 pH unit of the overall pH, and there was no statistically significant difference among the time ranges.

TABLE 4. Average pH values of data grouped by wind speed and volume of precipitation, compared to overall figures.

	Avg	SD	n
Wind Speed			
0-5 km h^{-1}	4.1	0.45	58
6-44 km h^{-1}	4.4	0.45	249
$\geq$ 45 km h^{-1}	4.8	0.38	21
Depth			
$\leq$ 2 mm	4.3	0.50	96
2.1-9.9 mm	4.4	0.44	132
$\geq$ 10 mm	4.6	0.44	135
Overall	4.4	0.48	363

pH VALUES OF MIXTURES CONTAINING VARIOUS PROPORTIONS OF RAIN OR SNOW AND LAKE WATER

This portion of the investigation is primarily concerned with the question: how much rain or snow must be added to a lake to bring about a biologically significant reduction in its pH value?

According to Evans et al. (1981), the biological effects of acidification are detectable below pH 6.0 and fisheries are severely impacted below pH 5.0.

The problem is not quite as simple as it first appears. It has been shown that there is considerable variation in pH values of rain and snow; it will be shown in a later report that as the seasons change, there are also considerable differences in the pH of the lake. As a result of this, the question must be asked many times using different lots of rain and water taken from the lake at different times of the year. It is also realized that in reality only a small proportion of the rain falls directly into a lake and that a much larger amount comes down onto the surrounding drainage area from which it later runs into the lake. This prior contact between the rain and the drainage area can also alter its pH.

This present section deals only with the pH resulting from mixing measured amounts of rain or melted snow with lake water at various periods of the year. Thirteen lots of rain and seven lots of snow altered the pH of water taken from Micmac Lake (Figs. 12 and 13, and Appendix Tables D-4 and D-5). Several interesting, but not unexpected, observations can be made about these results. First, melted snow has not as great a capacity as rain to lower pH of the lake waters. However, it has already been shown that pH of snow is higher than that of rain. Second, there is a greater difference in the capacity of different lots of rain to reduce the pH of the lake, than for different lots of snow. Here again, the variation in pH of different rain samples is greater than the variation in pH of different lots of melted snow.

What is really surprising are the relatively large amounts of rain and snow required to bring about serious reductions in pH of the lake water. This is particularly so in the case of snow. Even mixtures containing up to 50% or 60% melted snow had relatively small reductions in pH. The reduction in pH was considerably steeper when rain water was added. But even with the most acidic of the rains, up to 20% or 30% did not lower pH values to levels that would be considered biologically harmful.

This suggests that the lake water is well buffered against changes in pH, a hypothesis which is supported by the work of Gordon et al. (1981), who found that the alkalinity of Micmac Lake is relatively high.

DISCUSSION

Considering that pH 5.6 is accepted as normal for rain, there was a surprisingly large number of low pH values for snow and rain falling in this area in 1980 and 1981. Less than one percent of the samples was above pH 5.6; 33% was below 4.3 and 16% was below 4.0. None of the rain sampled would be likely to damage plants directly (Haines et al. 1980). However, it is not known whether there is a loss of nutrients from foliage and soil during the acidic precipitation which could prove to be detrimental to terrestrial plant growth in the long term. It is also not yet known whether metals which might be toxic are being introduced in dangerous quantities into the lakes and streams. It appears that Micmac Lake is well buffered and, in the short term, a normal volume of rainfall is unlikely to reduce the pH to any biologically significant degree. However, other workers have indicated that areas in which the volume-adjusted annual pH is less than 4.6 are in danger of being deleteriously affected over time (Evans et al. 1981). The volume-adjusted pH for Micmac Lake precipitation in 1981 was only 4.3.

There is a definite seasonal trend in pH values of precipitation, with rain being most acid in summer, least acid in winter, and intermediate in acidity in spring and autumn. This is explained to a large extent by seasonal variation in wind direction.

Unquestionably, wind direction at the time of precipitation does affect pH of rain and snow in this location. Winds from northerly and easterly directions were accompanied by rain and snow with higher pH values than winds from southerly and westerly directions. When wind direction changes during a precipitation, pH often also changes. There is evidence that a change to the south or west tends to result in a drop in pH, while a change to north or east tends to result in an increase in pH. However, even when wind direction remains constant there is a tendency for pH to increase with time.

It is tempting to point out that winds from north and east blow off the Atlantic Ocean, while winds from the south and west may carry atmospheric pollution from the cities of Dartmouth and Halifax, and especially from the power plants in Halifax and at Tuft's Cove in Dartmouth, as well as from the refineries at Eastern Passage (Fig. 1). However, there is nothing in the data recorded to prove that the apparent greater pollution from the south and west did not have its origin in industrial areas many hundreds of miles distant from this area (Fig. 2). The data presented by Underwood (1981) indicate that, throughout the length of the province, precipitation accompanied by southwest winds is the most acidic, while that which comes from the north and east is the least acidic. However, the average pH of precipitation in other regions ranges from 4.5 to 5.0. It would seem, therefore, that there is a background of air pollution coming from distant regions but that acidity is increased by pollution sources in the Halifax-Dartmouth area.

Factors other than wind direction have also been investigated. Snow was found to have significantly higher pH values than rain. The pH of precipitation was significantly greater if the amount was relatively large. This was not unexpected, since acids present in a body of air would be increasingly diluted as the volume of precipitation increases. There was a significantly higher average pH in events accompanied by high wind speed than in precipitation through calm or slow moving air, irrespective of wind direction. Variation in pH with the type of frontal system has been noted in other studies (Raynor and Hayes 1981). The time of day of precipitation was not correlated with pH.

ACKNOWLEDGEMENTS

We wish to thank Dr. J.E. Stewart for his support and encouragement, and Mr. N. Whynot for preparing the figures.

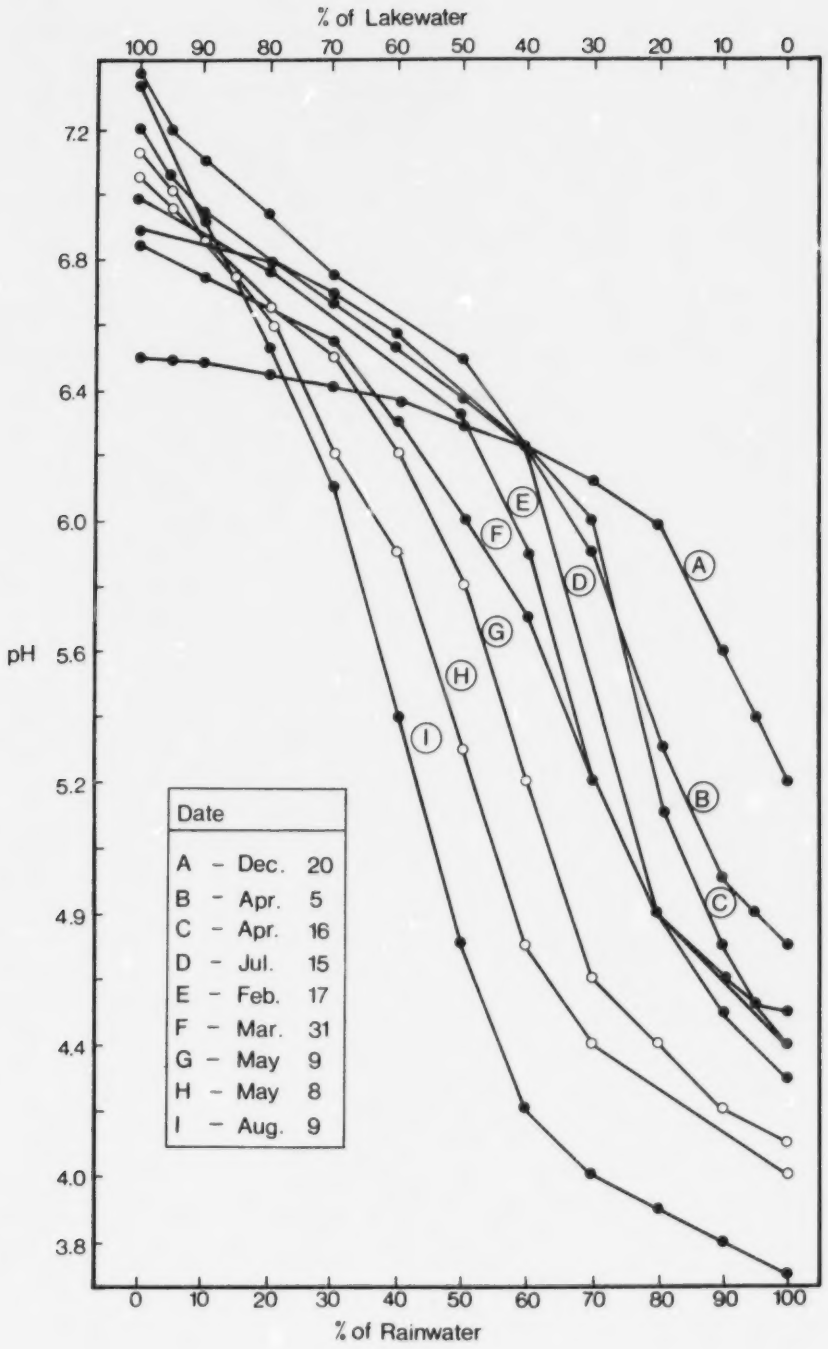

FIG. 12 The pH resulting from various mixtures of rain and lake water.

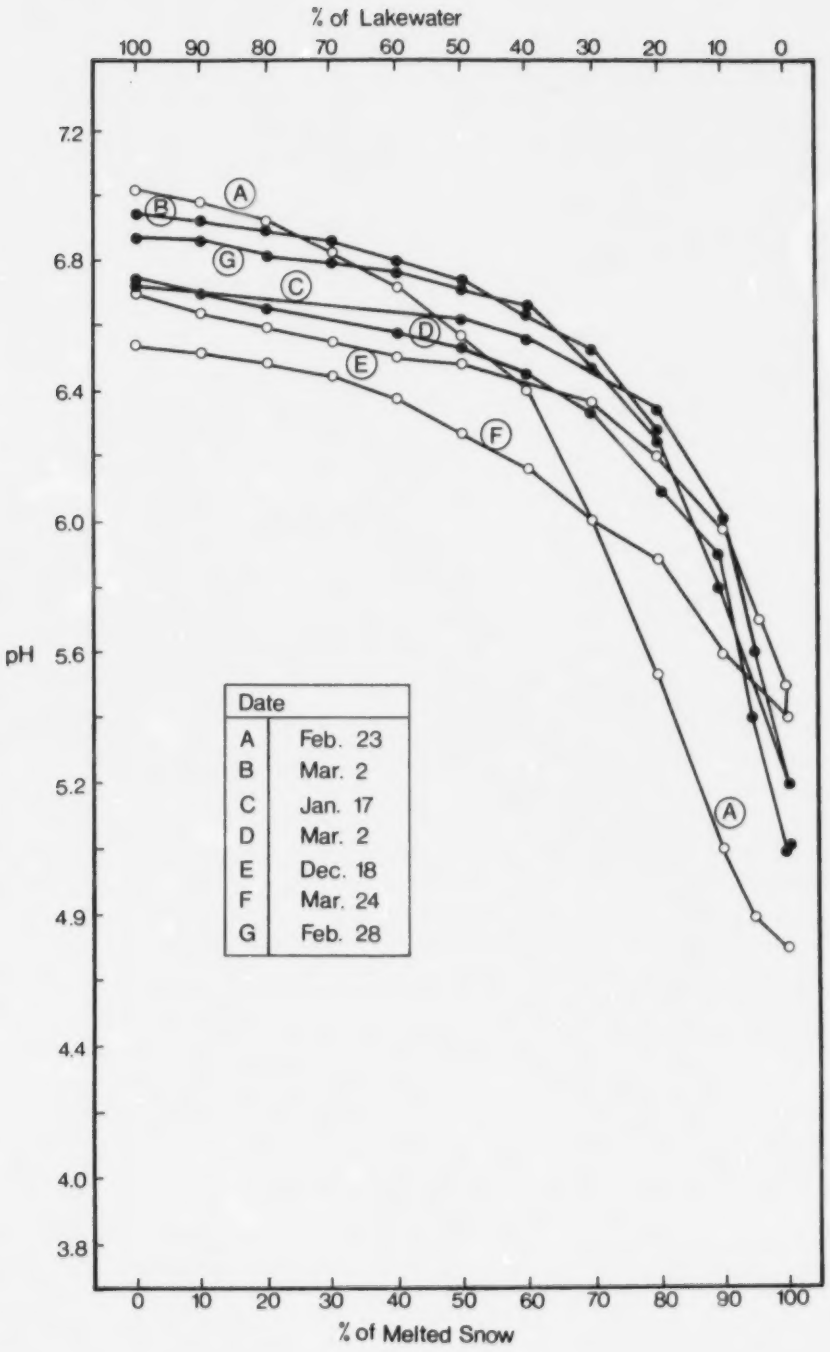

FIG. 13 The pH resulting from various mixtures of snow and lake water.

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APPENDIX A

LIST OF PRECIPITATION EVENTS (MICMAC LAKE,1980-81)

YEAR	MONTH	DAY	COLLECTION TIME	PH	WIND	RAIN OR SNOW	WIND SPEED	VOLUME ML	DEPTH MM	TIME OF DAY OF PRECIPITATION	
1980											
	1	11	1600	4.3	E	RAIN	1	9999	1.6	0600-1800	
	1	16	1645	5.4	NNE	SNOW	2	9999	7.2	0600-1800	
	1	17	9999	5.1	ENE	SNOW	2	9999	1.2	0000-1200	9
	1	18	9999	5.2	E	SNOW	2	9999	3.2		
	1	19	1530	4.5	N	RAIN	2	9999	13.4	0600-1800	
	1	20	9999	4.4	NW	SNOW	2	9999	99.9		9
	1	23	1600	5.0	SE	SNOW	2	9999	27.4	1800-0600	
	2	17	1315	4.4	S	RAIN	2	9999	2.2	0000-1200	
	2	23	930	4.9	SE	SNOW	2	9999	8.4		9
	2	28	1200	5.2	NE	SNOW	2	9999	12.0	1800-0600	
	3	2	1200	5.2	W	SNOW	2	9999	99.9	0000-1200	
	3	6	1030	4.3	SSW	RAIN	2	9999	6.6	0000-1200	
	3	8	1730	4.4	ENE	RAIN	2	9999	30.8	1200-0000	
	3	9	945	4.6	NNE	RAIN	1	9999	11.0	1800-0600	
	3	11	1645	4.8	E	RAIN	3	9999	12.6	1200-0000	
	3	12	2345	4.6	SW	SNOW	2	9999	1.2	0000-1200	
	3	13	1610	4.4	WNW	RAIN	2	9999	99.9	0600-1800	
	3	14	1930	4.4	E	RAIN	3	9999	21.2	1200-0000	
	3	16	1530	4.8	WNW	SNOW	2	9999	99.9	0600-1800	
	3	18	1930	4.4	SSE	RAIN	3	9999	20.1	1200-0000	
	3	20	1230	4.6	NW	RAIN	2	9999	99.9	0000-1200	
	3	24	930	5.4	N	SNOW	3	9999	5.8	1200-0000	
	3	27	930	4.1	NNE	RAIN	2	9999	5.0		9
	3	30	930	4.3	NNE	RAIN	2	9999	7.4	1200-0000	
	4	3	900	3.7	SSW	RAIN	1	140	1.8	0000-1200	
	4	5	1330	4.6	SSE	RAIN	3	9999	17.8	1800-0600	
	4	11	1230	4.8	ESE	RAIN	2	9999	19.3	0000-1200	
	4	12	1500	4.2	W	RAIN	2	9999	.6		9
	4	13	1500	4.2	W	RAIN	2	9999	3.5	1800-0600	
	4	16	1400	4.4	SSW	RAIN	2	9999	21.8	0000-1200	
	4	17	1100	3.7	99	RAIN	2	9999	99.9	0000-1200	
	4	21	1900	4.6	S	RAIN	2	9999	18.0	1200-0000	
	4	22	1600	4.7	E	RAIN	3	9999	22.4	0600-1800	
	4	23	1530	4.9	E	RAIN	2	9999	12.8	0600-1800	
	4	24	1530	4.7	N	RAIN	2	9999	99.9	0600-1800	
	4	30	1030	4.8	E	RAIN	2	9999	9.5	0000-1200	
	4	30	1300	5.1	ENE	RAIN	2	9999	9.5	0600-1800	
	5	1	1015	4.3	E	RAIN	2	9999	99.9	1200-0000	
	5	8	1400	4.0	E	RAIN	2	9999	28.0	0600-1800	
	5	9	1410	4.1	SSE	RAIN	2	9999	23.2	0600-1800	

WIND SPEED 1= PREDOMINANTLY 0-5KPH. 2= 6-44KPH. 3= 45 OR MORE KPH
MISSING DATA CODED AS 9 OR MULTIPLE 9S
DEPTH TAKEN FROM SHEARWATER DATA IF MISSING FOR MICMAC LAKE

YEAR	MONTH	DAY	COLLECTION TIME	PH	WIND	RAIN OR SNOW	WIND SPEED	VOLUME ML	DEPTH MM	TIME OF DAY OF PRECIPITATION
1980										
	5	19	1040	3.9	S	RAIN	2	9999	7.8	0000-1200
	5	22	1530	4.4	SW	RAIN	2	9999	3.3	1200-0000
	5	28	1630	4.3	S	RAIN	2	9999	6.0	1200-0000
	6	1	1000	3.8	SSE	RAIN	2	9999	5.2	0000-1200
	6	4	1030	4.6	NE	RAIN	2	9999	6.2	0000-1200
	6	4	1345	4.7	N	RAIN	2	9999	6.2	0600-1800
	6	5	1020	4.5	NNW	RAIN	2	9999	13.2	0000-1200
	6	8	940	4.7	E	RAIN	2	9999	14.0	0000-1200
	6	9	900	4.1	WSW	RAIN	2	9999	.4	0000-1200
	6	15	1055	4.5	SE	RAIN	2	9999	26.4	1800-0600
	6	16	945	3.7	S	RAIN	2	9999	1.6	0000-1200
	6	21	1000	4.5	SSE	RAIN	2	9999	7.5	0000-1200
	6	25	845	3.9	SW	RAIN	1	9999	2.4	1200-0000
	6	30	1235	4.5	ESE	RAIN	2	9999	13.2	0000-1200
	6	30	1400	4.2	E	RAIN	2	9999	5.1	1200-0000
	6	30	1730	4.0	SW	RAIN	2	9999	5.1	1200-0000
	7	9	910	4.1	ESE	RAIN	2	1350	17.3	1800-0600
	7	9	1345	3.8	SSE	RAIN	1	130	1.7	0600-1800
	7	12	2015	4.0	E	RAIN	2	9999	12.3	1200-0000
	7	13	1830	4.3	SSE	RAIN	2	9999	4.3	1200-0000
	7	14	1400	4.3	SW	RAIN	2	9999	99.9	0600-1800
	7	16	815	3.8	SSW	RAIN	2	9999	.6	1800-0600
	7	20	1535	3.7	SSW	RAIN	2	70	.9	1200-0000
	7	22	1200	4.1	S	RAIN	1	15	.2	0600-1800
	7	30	1445	4.2	S	RAIN	2	9999	3.2	1200-0000
	8	4	845	3.3	SW	RAIN	1	260	3.3	1800-0600
	8	9	1030	3.7	S	RAIN	1	9999	6.0	0000-1200
	8	12	1225	4.7	SW	RAIN	1	9999	6.6	0000-1200
	8	12	1900	3.8	S	RAIN	2	9999	5.0	1200-0000
	8	16	1925	4.7	NNW	RAIN	2	9999	.6	1200-0000
	8	26	900	4.4	W	RAIN	1	9999	2.4	0000-1200
	8	26	1255	4.4	WSW	RAIN	1	9999	2.4	0000-1200
	8	27	1200	3.6	WSW	RAIN	1	9999	99.9	0000-1200
	8	28	1040	4.3	N	RAIN	2	9999	5.2	0000-1200
	9	14	1330	3.4	SE	RAIN	1	9999	99.9	0000-1200
	9	14	2030	3.8	S	RAIN	2	9999	15.2	1200-0000
	9	14	2400	4.5	SSW	RAIN	2	9999	15.2	1200-0000
	9	15	1130	4.5	W	RAIN	2	9999	11.0	0000-1200
	9	17	2250	4.5	SE	RAIN	2	9999	3.8	0000-1200
	9	19	950	3.7	NNW	RAIN	2	9999	.2	1800-0600
	9	21	1115	3.7	SSW	RAIN	2	9999	1.0	0000-1200
	9	23	1615	3.6	SSW	RAIN	1	9999	3.2	0000-1200
	9	24	1340	4.3	NNW	RAIN	2	9999	99.9	1200-0000

WIND SPEED 1= PREDOMINANTLY 0-5KPH, 2= 6-44KPH, 3= 45 OR MORE KPH
MISSING DATA CODED AS 9 OR MULTIPLE 9S
DEPTH TAKEN FROM SHEARWATER DATA IF MISSING FOR MICMAC LAKE

YEAR	MONTH	DAY	COLLECTION TIME	PH	WIND	RAIN OR SNOW	WIND SPEED	VOLUME ML	DEPTH MM	TIME OF DAY OF PRECIPITATION
1980	9	26	1145	5.1	ENE	RAIN	2	9999	20.0	0000-1200
	9	26	1715	4.4	SSE	RAIN	2	9999	19.7	1200-0000
	10	3	1530	3.8	SSW	RAIN	2	9999	.2	0600-1800
	10	4	1130	4.8	ESE	RAIN	2	9999	11.1	0600-1800
	10	4	1420	4.8	S	RAIN	2	9999	11.1	0600-1800
	10	6	1100	4.2	ENE	RAIN	2	9999	99.9	0000-1200
	10	7	1115	5.2	NE	RAIN	2	9999	16.8	0000-1200
	10	12	1210	4.0	SSE	RAIN	2	9999	.2	0000-1200
	10	13	830	4.4	W	RAIN	2	9999	12.6	0000-1200
	10	18	2030	4.3	SW	RAIN	2	9999	16.6	1200-0000
	10	19	1030	4.6	W	RAIN	2	9999	1.2	1800-0600
	10	25	1550	4.4	ESE	RAIN	2	9999	1.0	1200-0000
	10	27	1355	4.3	W	RAIN	2	9999	.4	0000-1200
	11	1	1210	3.8	SW	RAIN	2	9999	99.9	0000-1200
	11	5	1345	4.3	S	RAIN	2	475	6.1	0600-1800
	11	5	1510	4.7	SE	RAIN	2	150	1.9	1200-0000
	11	5	1600	4.3	S	RAIN	2	55	.7	1200-0000
	11	5	1700	4.2	WSW	RAIN	2	18	.2	1200-0000
	11	5	1920	4.3	WNW	RAIN	2	95	1.2	1200-0000
	11	8	900	3.8	SSE	RAIN	2	150	1.9	0000-1200
	11	8	1530	4.2	SSW	RAIN	2	9999	99.9	0600-1800
	11	10	1430	4.4	ENE	RAIN	2	9999	12.4	0600-1800
	11	10	2130	4.6	N	RAIN	2	9999	12.4	1200-0000
	11	11	1600	4.7	NNW	RAIN	2	9999	4.2	9
	11	14	1145	4.3	W	RAIN	2	9999	3.0	0000-1200
	11	18	1200	4.6	ESE	SNOW	2	9999	99.9	0600-1800
	11	18	1440	4.9	E	SNOW	2	9999	4.2	0600-1800
	11	18	1710	5.1	E	SNOW	2	9999	8.4	1200-0000
	11	18	2005	5.5	ENE	SNOW	3	9999	8.4	1200-0000
	11	19	950	5.0	N	SNOW	3	9999	1.8	0000-1200
	11	22	1000	4.4	E	RAIN	2	9999	2.3	0000-1200
	11	22	1200	4.9	NE	RAIN	2	9999	2.3	0000-1200
	11	23	1000	4.4	N	RAIN	2	9999	99.9	1800-0600
	11	26	1030	4.7	ESE	RAIN	2	9999	19.2	1800-0600
	11	27	1000	5.1	N	SNOW	3	9999	1.0	0000-1200
	11	29	1225	5.2	NE	RAIN	3	9999	17.1	0000-1200
	11	29	1420	4.4	SSW	RAIN	2	9999	17.1	1200-0000
	11	30	1530	3.8	WSW	RAIN	1	9999	2.4	0600-1800
	12	1	1635	3.8	SSE	RAIN	2	9999	1.2	1200-0000
	12	3	2200	4.3	ESE	RAIN	3	9999	26.6	0600-1800
	12	5	1025	3.8	NNW	RAIN	2	9999	.2	0000-1200
	12	9	1000	4.0	SSW	RAIN	2	9999	3.7	0000-1200
	12	10	1000	4.6	NW	SNOW	1	9999	.2	1800-0600

WIND SPEED 1= PREDOMINANTLY 0-5KPH, 2= 6-44KPH, 3= 45 OR MORE KPH
MISSING DATA CODED AS 9 OR MULTIPLE 9S
DEPTH TAKEN FROM SHEARWATER DATA IF MISSING FOR MICMAC LAKE

YEAR	MONTH	DAY	COLLECTION TIME	PH	WIND	RAIN OR SNOW	WIND SPEED	VOLUME ML	DEPTH MM	TIME OF DAY OF PRECIPITATION
1980										
	12	11	1000	4.4	NW	SNOW	1	9999	1.0	0000-1200
	12	13	1200	4.2	E	SNOW	2	9999	5.0	1800-0600
	12	14	1010	3.6	W	RAIN	2	9999	.6	0000-1200
	12	17	1000	5.8	NE	SNOW	2	9999	12.2	0600-1800
	12	17	1230	5.4	WNW	SNOW	1	9999	1.0	0000-1200
	12	19	1610	3.8	SW	RAIN	2	9999	3.4	1200-0000
	12	22	1045	4.5	WNW	SNOW	2	9999	.2	1200-0000
	12	23	1520	4.4	SE	SNOW	2	9999	10.6	1200-0000
	12	24	1025	4.5	SE	SNOW	2	9999	6.0	1800-0600
	12	25	850	3.8	WSW	RAIN	1	9999	.9	0000-1200
	12	25	1700	4.2	NW	RAIN	2	9999	.9	1200-0000
	12	27	1130	4.4	S	SNOW	2	9999	3.5	0000-1200
	12	28	1130	4.4	NNW	SNOW	1	9999	99.9	1800-0600
	12	30	1500	5.3	ENE	RAIN	2	9999	48.9	0600-1800
N	140	140	137	140	139	140	140	12	140	134
MEAN				4.4						
STDEV				.47						
1981										
	1	2	1915	5.7	NE	SNOW	2	9999	17.2	1200-0000
	1	3	1200	5.5	NW	SNOW	2	9999	2.6	1800-0600
	1	4	1220	4.7	W	SNOW	2	9999	6.0	1800-0600
	1	7	2000	5.2	SE	RAIN	3	150	1.9	1200-0000
	1	8	1015	4.7	SW	RAIN	2	9999	99.9	0000-1200
	1	10	1545	5.3	NE	SNOW	2	9999	31.5	0600-1800
	1	12	1430	5.0	SW	RAIN	1	9999	1.8	0600-1800
	1	13	1345	5.2	N	SNOW	2	9999	12.2	1800-0600
	1	16	1045	4.3	NNW	SNOW	2	9999	2.8	1800-0600
	1	17	1000	4.5	NE	SNOW	1	230	2.9	1800-0600
	1	17	1700	4.9	NNE	SNOW	2	985	12.6	0600-1800
	1	17	2235	5.2	N	SNOW	2	4770	61.2	1200-0000
	2	3	2130	4.5	SSW	RAIN	3	950	12.2	0600-1800
	2	5	1215	4.0	NE	SNOW	2	120	1.5	0000-1200
	2	5	1905	4.2	N	SNOW	2	165	2.1	0600-1800
	2	7	1030	4.3	SW	SNOW	2	275	3.5	0000-1200
	2	8	1630	4.3	E	RAIN	2	2740	35.1	1200-0000
	2	12	930	4.3	S	RAIN	3	490	6.3	0000-1200
	2	12	1130	4.8	SSW	RAIN	3	220	2.8	0000-1200
	2	26	1150	4.4	N	RAIN	2	435	5.6	1800-0600

WIND SPEED 1= PREDOMINANTLY 0-5KPH, 2= 6-44KPH, 3= 45 OR MORE KPH
MISSING DATA CODED AS 9 OR MULTIPLE 9S
DEPTH TAKEN FROM SHEARWATER DATA IF MISSING FOR MICMAC LAKE

YEAR	MONTH	DAY	COLLECTION TIME	PH	WIND	RAIN OR SNOW	WIND SPEED	VOLUME ML	DEPTH MM	TIME OF DAY OF PRECIPITATION
1981										
	2	27	1130	5.0	NNE	RAIN	2	580	7.4	1800-0600
	3	2	1605	3.9	WSW	RAIN	2	85	1.1	1200-0000
	3	11	950	4.4	NNE	SNOW	1	340	4.4	0000-1200
	3	14	1730	3.8	ESE	RAIN	2	140	1.8	1200-0000
	3	15	1400	4.5	NW	SNOW	3	1720	22.1	0600-1800
	3	16	930	4.7	NW	SNOW	2	43	.6	1800-0600
	3	17	855	4.7	E	RAIN	2	2740	35.1	1800-0600
	3	17	2110	4.7	ENE	RAIN	2	220	2.8	0000-1200
	3	21	930	4.9	N	SNOW	3	650	8.3	0000-1200
	3	21	1815	5.1	NNE	SNOW	3	180	2.3	0600-1800
	3	28	915	4.3	NW	SNOW	2	540	6.9	1800-0600
	3	31	900	4.7	SSW	RAIN	2	2540	32.6	1800-0600
	3	31	1200	4.7	SW	RAIN	2	780	10.0	0000-1200
	4	2	1500	4.3	SE	RAIN	3	180	2.3	1200-0000
	4	3	845	4.3	W	RAIN	2	125	1.6	1800-0600
	4	6	1740	4.3	SSW	RAIN	2	735	9.4	0600-1800
	4	10	900	4.4	SSW	RAIN	2	325	4.2	0000-1200
	4	11	1900	4.5	SSW	RAIN	2	33	.4	1200-0000
	4	14	2215	4.7	S	RAIN	2	95	1.2	1200-0000
	4	15	500	4.5	S	RAIN	3	610	7.8	1800-0600
	4	18	900	3.9	SSE	RAIN	1	255	3.3	1800-0600
	4	18	2000	3.7	ESE	RAIN	1	205	2.6	0600-1800
	4	21	900	4.4	NNE	SNOW	2	700	9.0	1800-0600
	4	24	1000	4.7	SE	RAIN	2	300	3.8	0000-1200
	4	24	1235	4.9	ENE	RAIN	2	870	11.2	0000-1200
	4	24	1435	5.1	NE	RAIN	2	140	1.8	0600-1800
	4	24	1735	4.4	ENE	RAIN	2	95	1.2	0600-1800
	4	25	820	4.5	N	RAIN	2	270	3.5	1800-0600
	4	29	1800	3.8	SE	RAIN	2	250	3.2	1200-0000
	4	30	1000	3.6	S	RAIN	2	775	9.9	0000-1200
	5	2	1030	4.7	NNE	RAIN	2	815	10.4	1800-0600
	5	3	1640	5.1	NNE	RAIN	2	2650	34.0	0600-1800
	5	4	1145	4.7	NNE	RAIN	2	420	5.4	0000-1200
	5	5	1840	4.4	E	RAIN	2	640	8.2	0600-1800
	5	6	930	4.3	E	RAIN	2	85	1.1	1800-0600
	5	7	940	4.0	S	RAIN	1	220	2.8	0000-1200
	5	7	1500	4.8	E	RAIN	2	136	1.7	0600-1800
	5	12	1330	4.1	ESE	RAIN	1	310	4.0	0600-1800
	5	13	1230	4.7	E	RAIN	2	750	9.6	1800-0600
	5	13	1900	4.8	SSE	RAIN	2	525	6.7	1200-0000
	5	17	845	4.4	SSE	RAIN	2	1220	15.6	0000-1200
	5	17	1300	4.2	S	RAIN	2	520	6.7	0000-1200
	5	22	2300	5.1	NE	RAIN	2	955	12.2	1200-0000

WIND SPEED 1= PREDOMINANTLY 0-5KPH, 2= 6-44KPH, 3= 45 OR MORE KPH
MISSING DATA CODED AS 9 OR MULTIPLE 9S
DEPTH TAKEN FROM SHEARWATER DATA IF MISSING FOR MICMAC LAKE

YEAR	MONTH	DAY	COLLECTION TIME	PH	WIND	RAIN OR SNOW	WIND SPEED	VOLUME ML	DEPTH MM	TIME OF DAY OF PRECIPITATION
1981										
	5	23	2135	5.2	NNE	RAIN	2	4545	58.3	9
	5	24	1545	5.3	N	RAIN	2	1462	18.7	1800-0600
	5	30	1230	4.5	SSE	RAIN	1	950	12.1	0000-1200
	5	31	2100	4.0	SSW	RAIN	1	415	5.3	1200-0000
	6	4	930	3.9	SSW	RAIN	1	380	4.9	0000-1200
	6	4	1145	4.0	SSE	RAIN	1	85	1.1	0000-1200
	6	5	915	4.2	SSW	RAIN	1	1030	13.2	0000-1200
	6	6	2300	4.0	SSE	RAIN	2	300	3.8	1200-0000
	6	7	1700	4.2	NW	RAIN	2	70	.9	1200-0000
	6	8	930	4.9	WNW	RAIN	1	275	3.5	1800-0600
	6	9	1830	4.4	SSE	RAIN	2	2955	37.9	1200-0000
	6	9	2200	4.6	WSW	RAIN	1	1230	15.8	1200-0000
	6	10	845	4.7	W	RAIN	2	750	9.6	1800-0600
	6	16	1915	4.9	SSE	RAIN	2	110	1.4	0600-1800
	6	17	900	4.3	SW	RAIN	1	1230	15.8	1800-0600
	6	18	500	4.0	NW	RAIN	1	410	5.3	1800-0600
	6	21	1600	4.4	S	RAIN	1	3135	40.2	9
	6	22	700	3.7	SW	RAIN	2	325	4.2	1800-0600
	6	26	1340	3.8	S	RAIN	2	1030	13.2	1800-0600
	7	1	1800	4.2	SSE	RAIN	2	570	7.3	1200-0000
	7	5	2345	4.4	SSE	RAIN	1	1750	22.4	1200-0000
	7	6	830	4.2	SSW	RAIN	2	445	5.7	0000-1200
	7	10	1000	3.8	SSW	RAIN	1	105	1.3	0000-1200
	7	13	2200	4.1	ESE	RAIN	2	205	2.6	1200-0000
	7	14	900	4.3	SSW	RAIN	2	1070	13.7	0000-1200
	7	14	2305	4.1	W	RAIN	2	520	6.7	1200-0000
	7	15	815	4.7	WSW	RAIN	2	750	9.6	0000-1200
	7	21	1440	3.7	SW	RAIN	2	460	5.9	1200-0000
	7	21	1915	4.2	SE	RAIN	2	5340	68.5	1200-0000
	7	21	2140	4.0	S	RAIN	2	790	10.1	1200-0000
	7	27	1850	4.1	S	RAIN	2	1180	15.1	0600-1800
	7	27	2030	4.2	SSW	RAIN	2	170	2.2	1200-0000
	8	5	1100	3.8	S	RAIN	1	420	5.4	0000-1200
	8	5	2145	3.6	SSE	RAIN	1	600	7.7	1200-0000
	8	6	810	4.4	E	RAIN	2	2525	32.3	1800-0600
	8	7	1000	3.7	NW	RAIN	1	95	1.2	0000-1200
	8	8	1100	4.5	WNW	RAIN	1	155	2.0	0000-1200
	8	8	1350	4.5	SE	RAIN	1	135	1.7	0600-1800
	8	12	930	4.2	S	RAIN	2	27	.3	0000-1200
	8	12	1540	4.1	SSW	RAIN	2	832	10.7	0600-1800
	8	12	1645	4.6	WNW	RAIN	2	650	8.3	1200-0000
	8	12	2000	4.6	NW	RAIN	2	218	2.8	1200-0000
	8	15	1855	4.4	S	RAIN	2	1275	16.3	1200-0000

WIND SPEED 1= PREDOMINANTLY 0-5KPH, 2= 6-44KPH, 3= 45 OR MORE KPH
MISSING DATA CODED AS 9 OR MULTIPLE 9S
DEPTH TAKEN FROM SHEARWATER DATA IF MISSING FOR MICMAC LAKE

YEAR	MONTH	DAY	COLLECTION TIME	PH	WIND	RAIN OR SNOW	WIND SPEED	VOLUME ML	DEPTH MM	TIME OF DAY OF PRECIPITATION	
1981											
	8	15	2120	4.0	SSW	RAIN	2	235	3.0	1200-0000	
	8	15	2230	4.1	WSW	RAIN	2	385	4.9	1200-0000	
	8	16	905	3.9	WSW	RAIN	1	550	7.1	0600-1800	
	8	16	950	3.6	SE	RAIN	1	35	.4	0600-1800	
	8	16	1250	3.9	S	RAIN	1	1380	17.7	0600-1800	
	9	6	1150	5.5	NE	RAIN	2	395	5.1	0600-1800	
	9	9	1805	4.6	SE	RAIN	2	500	6.4	0600-1800	
	9	9	2000	4.7	SSE	RAIN	2	705	9.0	1200-0000	
	9	9	2210	4.1	S	RAIN	2	120	1.5	1200-0000	
	9	11	1250	3.8	WSW	RAIN	1	93	1.2	0600-1800	
	9	13	930	3.8	SW	RAIN	2	996	12.8	0000-1200	
	9	15	930	3.7	SW	RAIN	1	34	.5	0000-1200	
	9	15	2300	3.6	SW	RAIN	1	87	1.1	1200-0000	
	9	16	930	4.1	WNW	RAIN	1	685	8.8	1800-0600	
	9	16	1530	4.3	NW	RAIN	2	87	1.1	0600-1800	
	9	16	1740	4.5	NNW	RAIN	2	310	4.0	1200-0000	
	9	16	1955	4.6	N	RAIN	2	215	2.8	1200-0000	
	9	17	0020	4.9	NE	RAIN	2	835	10.7	1200-0000	
	9	17	830	4.9	NE	RAIN	2	395	5.1	0000-1200	
	9	19	1415	4.8	E	RAIN	2	675	8.7	1200-0000	
	9	19	1840	5.2	NE	RAIN	2	833	10.7	1200-0000	
	9	20	845	4.5	W	RAIN	2	330	4.2	1800-0600	
	9	23	845	4.4	S	RAIN	2	1560	20.0	0000-1200	
	9	23	1720	5.3	NE	RAIN	2	3395	43.5	0600-1800	
	9	24	1340	4.6	NE	RAIN	2	94	1.2	0600-1800	
	9	24	2000	4.6	SSE	RAIN	2	970	12.4	1200-0000	
	9	28	1440	3.8	SSW	RAIN	2	137	1.8	1200-0000	
	10	2	1200	4.0	SW	RAIN	2	275	3.5	0600-1800	
	10	2	1510	3.8	SSE	RAIN	2	160	2.1	1200-0000	
	10	2	1745	4.0	SW	RAIN	2	145	1.9	1200-0000	
	10	3	930	4.2	SW	RAIN	2	660	8.5	0000-1200	
	10	7	1130	3.8	SSE	RAIN	2	805	10.3	0600-1800	
	10	7	1400	4.0	SE	RAIN	2	1940	24.9	0600-1800	
	10	7	1545	4.2	SW	RAIN	2	965	12.4	1200-0000	
	10	8	1815	4.2	W	RAIN	2	505	6.5		9
	10	9	850	4.6	NW	RAIN	1	27	.3	0000-1200	
	10	16	2050	4.6	NE	RAIN	1	235	3.0		9
	10	17	830	4.9	NNE	RAIN	2	1550	19.9	1800-0600	
	10	19	1730	4.5	SW	RAIN	3	605	7.8	0600-1800	
	10	19	2200	4.5	W	RAIN	2	1200	15.4	1200-0000	
	10	20	830	4.4	NW	RAIN	2	180	2.3	0000-1200	
	10	24	1220	4.6	W	RAIN	2	155	2.0	1200-0000	
	10	24	1410	5.2	NNW	RAIN	2	47	.6	1200-0000	

WIND SPEED 1= PREDOMINANTLY 0-5KPH, 2= 6-44KPH, 3= 45 OR MORE KPH
MISSING DATA CODED AS 9 OR MULTIPLE 9S
DEPTH TAKEN FROM SEPARATEE DATA IF MISSING FOR MICMAC LAKE

YEAR	MONTH	DAY	COLLECTION TIME	PH	WIND	RAIN OR SNOW	WIND SPEED	VOLUME ml	DEPTH mm	TIME OF DAY OF PRECIPITATION
1981										
	10	26	1700	4.6	NSW	RAIN	2	913	11.2	0600-1800
	10	26	2145	4.7	SE	RAIN	2	410	5.3	1200-0000
	10	27	900	5.2	SE	RAIN	1	970	12.4	0000-1200
	10	27	2115	4.3	S	RAIN	2	410	5.3	1200-0000
	10	28	845	4.3	SW	RAIN	2	395	5.1	0600-1800
	10	28	1215	4.7	WSW	RAIN	2	340	4.4	0600-1800
	11	1	2100	4.0	SW	RAIN	2	22	.3	1200-0000
	11	6	1545	3.7	S	RAIN	2	182	2.3	1200-0000
	11	6	1710	4.4	SE	RAIN	2	400	5.1	1200-0000
	11	6	2000	4.2	S	RAIN	2	595	7.6	1200-0000
	11	6	2245	4.2	SW	RAIN	2	865	11.1	1200-0000
	11	7	830	4.6	S	RAIN	2	2225	28.5	0000-1200
	11	7	1100	4.4	SSW	RAIN	2	82	1.1	0600-1800
	11	7	2250	4.0	SW	RAIN	2	160	2.1	0600-1800
	11	11	845	3.3	S	RAIN	2	120	1.5	0000-1200
	11	11	1830	3.6	SW	RAIN	2	240	3.1	0600-1800
	11	11	2215	3.8	NW	RAIN	1	64	.8	1200-0000
	11	15	1235	5.2	ENE	RAIN	2	163	2.0	0600-1800
	11	15	1510	5.2	E	RAIN	2	318	4.1	1200-0000
	11	15	2030	5.2	ESE	RAIN	2	180	2.3	1200-0000
	11	16	930	4.6	ESE	RAIN	2	365	4.7	1800-0600
	11	16	1950	4.5	ENE	RAIN	2	842	10.8	1200-0000
	11	16	2200	4.8	NNE	RAIN	2	735	9.4	1200-0000
	11	17	850	4.9	SSE	RAIN	2	2390	30.6	1800-0600
	11	17	1515	4.3	W	RAIN	2	33	.4	0600-1800
	11	17	2400	4.5	NW	RAIN	2	130	1.7	1200-0000
	11	18	1300	4.2	NW	RAIN	2	205	2.6	0600-1800
	11	18	1640	4.0	N	RAIN	2	45	.6	1200-0000
	11	18	1925	3.7	S	RAIN	1	18	.2	1200-0000
	11	18	2100	4.0	SE	RAIN	1	153	2.0	1200-0000
	11	19	915	3.9	NW	RAIN	2	170	2.2	1800-0600
	11	20	2340	4.1	SE	RAIN	2	341	4.4	1200-0000
	11	21	1010	4.5	S	RAIN	2	6320	81.0	1800-0600
	11	21	1445	4.6	SW	RAIN	2	68	.9	0600-1800
	11	22	1410	3.7	SW	RAIN	2	22	.3	1200-0000
	11	26	830	4.4	N	RAIN	2	150	1.9	0600-1800
	11	28	945	3.6	99	RAIN	1	38	.5	0000-1200
	11	28	2000	6.1	N	RAIN	2	35	.4	1200-0000
	12	2	1910	4.6	SSE	RAIN	9	1833	23.5	1200-0000
	12	2	2100	4.8	S	RAIN	9	785	10.1	1200-0000
	12	3	1500	4.5	99	RAIN	1	2312	29.6	9
	12	3	1900	4.7	SE	RAIN	9	915	11.7	1200-0000
	12	3	2215	4.7	S	RAIN	9	1600	20.5	1200-0000

WIND SPEED 1= PREDOMINANTLY 0-5KPH, 2= 6-44KPH, 3= 45 OR MORE KPH
MISSING DATA CODED AS 9 OR MULTIPLE 9S
DEPTH TAKEN FROM SHEARWATER DATA IF MISSING FOR MICMAC LAKE

YEAR	MONTH	DAY	COLLECTION TIME	PH	WIND	RAIN OR SNOW	WIND SPEED	VOLUME ML	DEPTH MM	TIME OF DAY OF PRECIPITATION
1981										
	12	5	2300	5.5	N	RAIN	9	200	2.6	1200-0000
	12	6	900	5.5	SE	RAIN	9	2305	29.6	1800-0600
	12	7	900	4.4	E	RAIN	9	65	.8	0000-1200
	12	8	900	5.1	NW	RAIN	9	46	.6	1800-0600
	12	9	1500	4.8	N	RAIN	9	366	4.7	0600-1800
	12	9	1740	4.8	NNE	RAIN	9	287	3.7	1200-0000
	12	9	2200	4.8	NW	RAIN	9	250	3.2	1200-0000
	12	10	1200	5.1	N	RAIN	9	792	10.2	0600-1800
	12	10	1345	5.0	NNW	RAIN	9	5	.1	0600-1800
	12	11	900	4.5	NW	RAIN	9	89	1.1	1200-0000
	12	15	910	4.6	SE	SNOW	9	150	1.9	0000-1200
	12	15	1450	4.7	SE	RAIN	9	1680	21.5	1200-0000
	12	15	1710	4.9	SSE	RAIN	9	1530	19.6	1200-0000
	12	15	2200	4.5	SW	RAIN	9	395	5.1	1200-0000
	12	16	900	4.6	99	RAIN	9	3515	45.1	0000-1200
	12	16	1850	4.1	SW	RAIN	9	129	1.7	0600-1800
	12	18	2055	4.1	NNW	SNOW	9	83	1.1	0000-1200
	12	19	1000	4.6	NNE	SNOW	9	450	5.8	1800-0600
	12	22	1745	4.0	SW	RAIN	9	73	.9	1200-0000
	12	22	2000	4.4	NW	RAIN	9	190	2.4	1200-0000
	12	23	1930	4.3	SE	SNOW	9	1307	16.8	1200-0000
	12	23	2230	4.2	E	RAIN	9	235	3.0	1200-0000
	12	24	830	4.0	NNE	RAIN	9	105	1.3	0000-1200
	12	27	1130	5.2	E	SNOW	9	280	3.6	0000-1200
	12	27	1515	5.5	ENE	SNOW	9	385	4.7	0600-1800
	12	27	2300	5.6	E	SNOW	9	239	3.1	1200-0000
	12	28	1145	5.3	NNE	SNOW	9	930	11.9	0000-1200
	12	29	900	4.6	SSE	RAIN	9	475	6.1	0000-1200
	12	29	1230	4.4	SSW	RAIN	9	535	6.9	0600-1800
	12	29	1600	4.2	NW	RAIN	9	165	2.1	1200-0000
	12	30	940	4.5	N	SNOW	9	523	6.7	1800-0600
N	223	223	223	223	220	223	223	215	223	218
MEAN				4.5						
STDEV				.48						
TOTAL										
N	363	363	360	363	359	363	363	227	363	352
MEAN				4.4						
STDEV				.48						

WIND SPEED 1= PREDOMINANTLY 0-5KPH, 2= 6-44KPH, 3= 45 OR MORE KPH
MISSING DATA CODED AS 9 OR MULTIPLE 9S
DEPTH TAKEN FROM SHEARWATER DATA IF MISSING FOR MICMAC LAKE

APPENDIX B

FIVE-WAY ANALYSIS OF VARIANCE AND MULTIPLE CLASSIFICATION ANALYSIS

(i) ANALYSIS OF VARIANCE

Source of variation	Sum of squares	DF	Mean square	F	Signif. of F
Main effects	31.067	11	2.824	21.270	0.001
Season	0.352	3	0.117	0.884	0.450
Wind direction (sector)	10.837	3	3.612	27.206	0.001
Wind speed (range)	2.053	2	1.026	7.731	0.001
Amount of precipitation (range)	2.539	2	1.270	9.562	0.001
Type of precipitation	1.876	1	1.876	14.132	0.001
2-Way interactions	5.753	45	0.128	0.963	0.544
Season x direction	1.285	9	0.143	1.076	0.381
Season x wind speed	0.502	5	0.100	0.756	0.581
Season x amount	0.546	6	0.091	0.686	0.661
Season x type	0.055	2	0.027	0.206	0.814
Direction x wind speed	0.471	6	0.078	0.591	0.738
Direction x amount	0.871	6	0.145	1.093	0.367
Direction x type	0.348	3	0.116	0.875	0.455
Wind speed x amount	0.810	4	0.202	1.525	0.195
Wind speed x type	0.033	2	0.017	0.125	0.883
Amount x type	0.178	2	0.089	0.669	0.513
Explained	36.820	56	0.657	4.952	0.001
Residual	35.585	268	0.133		
Total	72.404	324	0.223		

(ii) MULTIPLE CLASSIFICATION ANALYSIS. Grand mean - 4.41

Variable category	N	Unadjusted deviation	ETA	Deviation adjusted for independents	BETA
Season					
Summer	57	-0.21		-0.06	
Autumn	121	0.00		0.03	
Winter	96	0.01		-0.02	
Spring	51	0.22		0.04	
			0.26		0.08
Wind direction (sector)					
NE	67	0.45		0.33	
SE	88	-0.01		-0.03	
SW	110	-0.28		-0.21	
NW	60	0.02		0.06	
			0.55		0.42
Wind speed (range)					
0-5 km/h	57	-0.27		-0.15	
6-44 km/h	247	0.03		0.02	
> 45 km/h	21	0.36		0.22	
			0.31		0.18
Amount of precipitation					
≤ 2 mm	87	-0.14		-0.12	
2.1-9.9 mm	118	-0.06		-0.04	
≥ 10 mm	120	0.16		0.12	
			0.27		0.21
Type od precipitation					
Rain	278	-0.07		-0.04	
Snow	47	0.41		0.23	
			0.36		0.20
Multipel R squared = 0.43					

APPENDIX C

CONSECUTIVE SAMPLING IN ONE RAIN-OR SNOWFALL

Month	Day(s)	Year	Time	Rain or snow	Wind	pH
3	14	1980	1610	R	E	4.3
			1930	R	E	4.5
3	30-31	1980	1000	R	NNE	4.2
			1300	R	NNE	4.3
			1800	R	NNE	4.2
			0930	R	NNE	4.5
4	23	1980	1000	R	E	5.3
			1530	R	E	4.7
4	30	1980	1030	R	E	4.8
			1300	R	ENE	5.1
5	9	1980	1000	R	SSE	4.2
			1410	R	SSE	4.1
			1600	R	SSE	3.9
6	4	1980	1030	R	NE	4.6
			1345	R	N	4.7
6	30	1980	0830	R	ESE	5.1
			1235	R	ESE	4.3
			1400	R	E	4.2
			1730	R	SW	4.0
7	9	1980	0910	R	ESE	4.1
			1345	R	SSE	3.8
8	12	1980	0900	R	SW	4.6
			1225	R	SW	4.8
			1900	R	S	3.8
8	26	1980	0900	R	W	4.4
			1255	R	WSW	4.4
9	14-15	1980	1330	R	SE	3.4
			2030	R	S	3.8
			2300	R	SSW	4.5
			1130	R	W	4.5
9	26	1980	1145	R	ENE	5.1
			1715	R	SSE	4.4
11	5	1980	1000	R	S	4.1
			1200	R	S	4.5
			1345	R	S	4.5
			1510	R	SE	4.7
			1600	R	S	4.3
			1700	R	WSW	4.2
			1920	R	WNW	4.3
11	8	1980	0900	R	SSE	3.8
			1530	R	SSW	4.2
11	10-11	1980	1430	R	ENE	4.4
			2110	R	N	4.6
			1000	R	NW	4.8
			1600	R	NNW	4.5
11	18-19	1980	1200	R	ESE	4.6
			1440	R	E	4.9
			1600	S	E	5.0
			1710	S	E	5.2
			1810	S	ENE	5.5
			2005	S	ENE	5.5
			0950	S	N	5.0
11	22-23	1980	1000	R	E	4.4
			1200	R	NE	4.9
11	29	1980	1225	R	NE	5.2
			1420	R	SSW	4.4
11	30	1980	1010	R	WSW	3.7
			1550	R	WSW	3.9
12	3	1980	1000	R	ESE	4.0
			1130	R	ESE	4.1
			1330	R	ESE	4.2
			1640	R	ESE	4.5
			2200	R	ESE	4.6
12	17	1980	1000	S	NE	5.8
			1100	S	WNW	5.5
			1230	S	WNW	5.4
12	19	1980	1330	R	SW	3.7
			1610	R	SW	4.0
12	25	1980	0850	R	WSW	3.8
			1700	R	NW	4.2
12	30	1980	1030	R	ENE	5.1
			1500	R	ENE	5.5
1	17	1981	1000	S	NE	4.5
			1315	S	NNE	4.7
			1505	S	NNE	4.8
			1700	S	NNE	5.1
			1930	S	N	5.1
			2115	S	N	5.2
			2235	S	N	5.3
2	5	1981	1215	S	NE	4.0
			1505	S	N	4.2
			1905	S	N	4.2
2	12	1981	0930	R	S	4.3
			1130	R	SSW	4.8
3	14-16	1981	1730	R	ESE	3.8
			1400	S	NW	4.5
			0930	S	NW	4.7
3	17	1981	0855	R	E	4.7
			1100	R	ENE	4.7
3	21	1981	0930	S	N	4.9
			1815	S	NNE	5.1
3	31	1981	0900	R	SSW	4.7
			1200	R	SW	4.7
4	2-3	1981	1500	R	SE	4.3
			0845	R	W	4.3
4	6	1981	0915	R	SSW	4.1
			1100	R	SSW	4.5
			1510	R	SSW	4.5
			1740	R	SSW	4.4
4	18	1981	0900	R	SSE	3.9
			2000	R	ESE	3.7

APPENDIX C, Continued

Month	Day(s)	Year	Time	Rain of snow	Wind	pH
4	24	1981	1000	R	SE	4.7
			1235	R	ENE	4.9
			1435	R	NE	5.1
			1730	R	ENE	4.4
5	3	1981	1300	R	NNE	5.1
			1640	R	NNE	5.1
5	5	1981	1000	R	E	4.4
			1840	R	E	4.4
5	7	1981	0940	R	S	4.0
			1500	R	NW	4.8
5	12	1981	0900	R	ESE	4.0
			1330	R	ESE	4.1
5	13	1981	1230	R	E	4.7
			1900	R	SSE	4.8
5	17	1981	0845	R	SSE	4.4
			1300	R	S	4.2
5	22	1981	0740	R	NE	4.9
			0920	R	NE	5.0
			1100	R	NE	5.3
5	23-24	1981	0900	R	NNE	5.3
			1240	R	NNE	4.8
			1430	R	NNE	4.9
			1550	R	NNE	4.6
			2135	R	NNE	4.9
			0730	R	N	5.3
			1545	R	N	5.0
6	4-5	1981	0930	R	SSW	3.9
			1145	R	SSE	4.0
			0915	R	SSW	4.2
6	9-10	1981	1530	R	SSE	4.0
			1830	R	SSE	4.5
			2200	R	WSW	4.6
			0845	R	W	4.7
6	16-17	1981	1915	R	SSE	4.3
			0900	R	SW	4.0
6	21-22	1981	0930	R	S	4.4
			1600	R	S	4.6
			0700	R	SW	3.7
6	26	1981	0930	R	S	3.7
			1340	R	S	4.0
7	5-6	1981	2345	R	SSE	4.4
			0830	R	SSW	4.2
7	13-15	1981	2200	R	ESE	4.1
			0900	R	SSW	4.3
			2305	R	W	4.1
			0815	R	WSW	4.7
7	21	1981	1440	R	SW	3.7
			1915	R	SE	4.2
			2140	R	S	4.0
7	27	1981	1145	R	S	4.0
			1340	R	S	4.1
			1850	R	S	4.1
			2030	R	SSW	4.2
8	5-6	1981	0830	R	S	3.9
			1100	R	S	3.8
			1430	R	SSE	3.6
			2145	R	SSE	3.8
			0810	R	E	4.4
8	8	1981	1100	R	WNW	4.5
			1350	R	S	4.5
8	12	1981	0930	R	S	4.2
			1215	R	SSW	4.0
			1330	R	SSW	4.2
			1540	R	SSW	4.6
			1645	R	WNW	4.6
			1830	R	NW	4.7
			2000	R	NW	4.3
8	16-17	1981	1620	R	S	4.5
			1730	R	S	4.3
			1855	R	S	4.5
			2120	R	SSW	4.0
			2230	R	WSW	4.1
			0905	R	WSW	3.9
			0950	R	SE	3.6
			1035	R	S	4.0
			1250	R	S	3.7
9	9	1981	1000	R	SE	4.5
			1805	R	SE	4.6
			2000	R	SSE	4.7
			2210	R	S	4.1
9	15-17	1981	0930	R	SW	3.7
			1100	R	SW	3.6
			0930	R	NW	4.3
			1530	R	WNW	4.1
			1740	R	NNW	4.5
			1955	R	N	4.6
			2155	R	NE	4.8
			0020	R	NE	5.0
			0830	R	NE	4.9
9	19-20	1981	1415	R	E	4.8
			1500	R	NE	5.1
			1615	R	NE	5.3
			1720	R	NE	5.2
			1840	R	NE	5.3
			0845	R	W	4.5
9	23-24	1981	0845	R	S	4.4
			1100	R	NE	5.3
			1230	R	NE	5.2
			1515	R	NE	5.5
			1720	R	NE	5.2
			1340	R	NE	4.6
			1530	R	SSE	4.6
			2000	R	SSE	4.7
10	2-3	1981	1200	R	SW	4.0
			1510	R	SSE	3.8
			1745	R	SW	4.0
			0930	R	SW	4.2

APPENDIX C, Continued

Month	Day(s)	Year	Time	Rain or snow	Wind	pH
10	7-8	1981	1130	R	SSE	3.8
			1400	R	SE	4.0
			1545	R	SW	4.2
			0900	R	W	4.2
			1815	R	W	4.1
10	16-17	1981	1830	R	NE	4.5
			2050	R	NE	4.7
			0830	R	NNE	4.9
10	19-20	1981	1730	R	SW	4.5
			2200	R	W	4.5
			0830	R	NW	4.4
10	24	1981	1220	R	W	4.6
			1410	R	NNW	5.2
10	26-28	1981	1500	R	ESE	4.6
			1700	R	ESE	4.6
			2145	R	SE	4.7
			0900	R	SE	5.2
			2115	R	S	4.3
			0845	R	SW	4.3
			1215	R	WSW	4.7
11	6-7	1981	1535	R	S	3.7
			1710	R	SE	4.4
			2000	R	S	4.2
			2245	R	SW	4.2
			0830	R	S	4.6
			1240	R	SSW	4.4
			2250	R	SW	4.0
11	11	1981	0845	R	S	3.3
			1630	R	SW	3.5
			1830	R	SW	3.7
			2215	R	NW	3.8
11	15-17	1981	1050	R	ENE	5.2
			1150	R	ENE	5.2
			1235	R	ENE	5.2
			1355	R	E	5.2
			1510	R	E	5.2
			2030	R	ESE	5.2
			0930	R	ESE	4.6
			1420	R	ENE	4.3
			1605	R	ENE	4.5
			1950	R	ENE	4.7
			2200	R	NNE	4.8
			0850	R	SSE	4.9
			1515	R	W	4.3
			2300	R	NW	4.5
11	18-19	1981	1300	R	NW	4.2
			1640	R	N	4.0
			1925	R	S	3.7
			2100	R	SE	4.0
			0915	R	NW	3.9
11	20-21	1981	2200	R	SE	3.7
			2340	R	SE	4.2
			1010	R	S	4.5
			1445	R	SW	4.6
12	2	1981	1335	R	SSE	4.6
			1540	R	SSE	4.5
			1910	R	SSE	4.7
			2100	R	S	4.8
12	3	1981	1000	R	Calm	4.5
			1500	R	Calm	4.6
			1640	R	SE	4.7
			1900	R	SE	4.7
			2000	R	S	4.7
			2110	R	S	4.9
			2215	R	S	4.7
12	5-6	1981	2030	R	N	5.3
			2130	R	N	5.9
			2400	R	N	?
			0900	R	SE	5.5
12	9-11	1981	0830	R	N	4.8
			1370	R	N	4.7
			1500	R	N	4.8
			1740	R	NNE	4.8
			2200	R	NW	4.8
			0920	R	N	5.1
			1200	R	N	5.1
			2030	R	NW	4.5
			0900	R	NW	4.5
12	15-16	1981	0910	S	SE	4.6
			1145	R	SE	4.6
			1450	R	SE	4.7
			1710	R	SSE	4.9
			2000	R	SW	4.4
			2200	R	SW	4.6
			0900	R	SSW	4.6
			1150	R	SW	4.4
			1410	R	SW	4.3
			1850	R	SW	3.8
12	18-19	1981	2055	S	NNW	4.1
			2230	S	NNE	4.7
			1000	S	NNE	4.5
12	22	1981	1745	R	SW	4.0
			2000	R	NW	4.4
12	23-24	1981	1515	S	SE	4.1
			1930	S	SE	4.5
			2230	R	E	4.2
			0830	R	NNE	4.0
12	27-28	1981	1130	S	E	5.2
			1515	S	ENE	5.5
			1915	S	E	5.6
			2300	S	E	5.5
			1145	S	NNE	5.3
12	29-30	1981	9000	R	SSE	4.6
			1230	R	SSW	4.4
			1600	R	NW	4.2
			1940	S	N	4.5
			0940	S	N	4.7

APPENDIX D

DATA TABLES FOR FIGURES 5, 6, 12 and 13

TABLE D-1. (for FIG. 5) Description of the precipitation events brought by the winds from each compass direction and sector. (The percentage of the total precipitation volume and VApH of events from each direction and sector are given for 1981 only. For 0.8% of events the wind was mixed or calm.)

Year	Compass Direct.	n	pH Avg	pH SD	pH min-max	% Freq	% Vol	VApH	Sector n	pH Mean	pH min - max	% Freq	% Vol	VApH
1980	N	(9)	4.7	0.38	4.3-5.4	6.4			NE (27)	4.9	4.1-5.8	19		
1981		(15)	4.8	0.56	4.0-6.1	8.5	7.0	4.9	(49)	4.9	4.0-6.1	22	24	4.9
Total		(24)	4.8	0.49	4.0-6.1	6.7			(76)	4.9	4.0-6.1	21		
1980	NNE	(4)	4.6	0.57	4.1-5.4	2.9								
1981		(15)	4.8	0.35	4.0-5.2	6.7	10.6	4.9						
Total		(19)	4.8	0.39	4.0-5.4	5.2								
1980	NE	(6)	5.2	0.40	4.6-5.8	4.3								
1981		(13)	5.0	0.46	4.0-5.7	5.8	5.3	5.0						
Total		(19)	5.0	0.44	4.0-5.8	5.2								
1980	ENE	(8)	4.9	0.48	4.2-5.5	5.7								
1981		(6)	4.9	0.42	4.4-5.5	2.7	1.5	4.8						
Total		(14)	4.9	0.44	4.2-5.5	3.9								
1980	E	(16)	4.6	0.38	4.0-5.2	1.4			SE (43)	4.5	3.4-5.2	31		
1981		(12)	4.7	0.44	4.3-5.6	5.4	7.8	4.7	(56)	4.5	3.6-5.6	25	34	4.4
Total		(28)	4.6	0.40	4.0-5.6	7.7			(100)	4.5	3.4-5.6	28		
1980	ESE	(8)	4.5	0.25	4.1-4.8	5.7								
1981		(7)	4.3	0.53	3.7-5.2	3.1	1.6	4.2						
Total		(16)	4.4	0.42	3.7-5.2	4.4								
1980	SE	(8)	4.5	0.47	3.4-5.0	5.7								
1981		(18)	4.5	0.50	3.6-5.5	8.1	12.0	4.3						
Total		(26)	4.5	0.48	3.4-5.5	7.1								
1980	SSE	(11)	4.1	0.31	3.8-4.6	7.9								
1981		(19)	4.4	0.41	3.6-4.9	8.5	12.6	4.3						
Total		(30)	4.3	0.39	3.6-4.9	8.9								
1980	S	(14)	4.2	0.33	3.7-4.8	10.0			SW (41)	4.1	3.3-4.8	29		
1981		(25)	4.2	0.38	3.3-4.8	11.2	17.9	3.9	(75)	4.2	3.3-5.0	34	35	4.0
Total		(38)	4.2	0.36	3.3-4.8	10.5			(116)	4.2	3.3-5.0	32		
1980	SSW	(10)	4.0	0.33	3.6-4.5	8.6								
1981		(19)	4.3	0.29	3.8-4.8	8.5	8.8	4.3						
Total		(31)	4.2	0.33	3.6-4.8	8.5								
1980	SW	(10)	4.1	0.43	3.3-4.7	7.1								
1981		(24)	4.2	0.38	3.6-5.0	10.8	6.2	4.1						
Total		(34)	4.1	0.39	3.3-5.0	9.4								
1980	WSW	(6)	4.0	0.30	3.6-4.4	4.3								
1981		(7)	4.2	0.41	3.8-4.7	3.1	2.4	4.3						
Total		(13)	4.1	0.37	3.6-4.7	3.6								
1980	W	(10)	4.4	0.40	3.6-5.2	7.1			NW (27)	4.4	3.6-5.4	19		
1981		(9)	4.4	0.23	4.2-4.7	4.0	2.5	4.4	(40)	4.4	3.7-5.5	18	7	4.3
Total		(19)	4.4	0.32	3.6-5.2	5.2			(67)	4.4	3.6-5.5	18		
1980	WNW	(5)	4.7	0.44	4.3-5.4	3.6								
1981		(5)	4.5	0.29	4.1-4.9	2.2	1.2	4.3						
Total		(10)	4.6	0.36	4.1-5.4	2.8								
1980	NW	(5)	4.4	0.17	4.2-4.6	3.6								
1981		(21)	4.4	0.42	3.7-5.5	9.4	3.3	4.3						
Total		(26)	4.4	0.38	3.7-5.5	7.2								
1980	NNW	(7)	4.3	0.40	3.7-4.7	5.0								
1981		(5)	4.6	0.47	4.1-5.2	2.2	0.3							
Total		(12)	4.4	0.44	3.7-5.2	3.3								

TABLE D-2 (for Fig.6) The percentage frequency of sampled precipitation events from each wind direction and sector in each season. (Where figures do not add up to 100% it is due to events of unknown wind direction.)

		% from each direction														
		NE Sector				SE Sector				SW Sector				NW Sector			
Season (n)	Year	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Winter																	
(29)	80	3.4	3.4	6.9	6.9	10.3	13.8	3.4	3.4	6.9	3.4	3.4	3.4	3.4	3.4	17.2	6.9
(58)	81	13.8	10.3	6.9	1.7	8.6	0.0	10.3	5.2	5.2	5.2	10.3	0.0	1.7	1.7	10.3	5.2
(87)	Total	10.3	8.0	6.9	3.4	9.2	4.6	8.0	4.6	5.7	4.6	8.0	1.1	2.3	2.3	12.6	5.7
Spring																	
(33)	80	6.1	9.1	0.0	6.1	21.2	3.0	0.0	9.1	9.1	9.1	6.1	0.0	9.1	6.1	3.0	0.0
(46)	81	6.5	15.2	4.3	6.5	8.7	6.9	6.5	8.7	10.9	10.9	2.2	2.2	2.2	0.0	8.7	0.0
(79)	Total	6.3	12.6	2.5	6.3	13.9	5.0	3.8	8.9	10.1	10.1	3.8	1.3	5.0	3.8	6.3	0.0
Summer																	
(31)	80	6.5	0.0	3.2	0.0	9.7	6.5	5.2	12.9	16.1	6.5	16.1	9.7	3.2	0.0	0.0	6.5
(44)	81	0.0	0.0	0.0	0.0	2.3	2.3	6.8	15.9	18.2	18.2	6.8	9.1	4.6	6.8	9.1	0.0
(75)	Total	2.7	0.0	1.3	0.0	5.3	4.0	6.7	14.7	17.3	13.3	10.6	9.3	4.0	4.0	5.3	2.7
Autumn																	
(47)	80	8.5	0.0	6.4	8.5	6.4	8.5	6.4	6.4	8.5	12.8	4.3	4.3	10.6	2.1	0.0	6.4
(75)	81	5.3	2.7	9.3	2.7	2.7	4.0	9.3	6.7	12.0	2.7	18.7	2.7	6.7	1.3	9.3	2.7
(122)	Total	6.5	1.6	8.2	4.9	4.1	15.7	8.2	6.6	10.6	6.6	13.1	3.3	8.2	1.6	5.7	4.1

TABLE D-3 for FIG. 6 Percentage frequency of the precipitation events from each wind sector and season of 1980 and 1981 which fall into each pH range.

			% in each pH range			
Season	Sector	n	pH 4.0	pH 4.0-4.25	pH 4.3-4.95	pH 5.0
Winter	NE	25	0	12	32	56
	SE	23	5	9	59	27
	SW	18	10	20	65	5
	NW	20	11	11	58	21
	?	1	0	0	100	0
	Total	87	6	13	53	29
Spring	NE	22	0	4	59	36
	SE	25	8	20	68	4
	SW	20	30	5	65	0
	NW	11	0	18	73	10
	?	1	100	0	0	0
	Total	79	11	11	65	13
Summer	NE	3	0	0	100	0
	SE	23	18	36	46	0
	SW	37	42	34	24	0
	NW	12	8	25	67	0
	?	0	0	0	0	0
	Total	75	28	32	40	0
Autumn	NE	27	0	7	52	41
	SE	31	10	17	60	13
	SW	41	39	24	37	0
	NW	23	13	22	70	4
	?	1	100	0	0	0
	Total	122	19	16	52	13
Overall		363	16	17	53	14

TABLE D-4(for FIG. 12) pH values obtained by mixing different proportions of rain and lake water.

Date	Percent of rain water												
1980	100	95	90	80	70	60	50	40	30	20	10	5	0
Feb 17	4.4	4.5	4.6	4.8	5.2	5.9	6.3	6.5	6.7	6.8	6.9	-	7.0
Mar 18	4.4	4.5	4.6	4.7	4.9	5.3	5.7	6.0	6.2	6.4	6.5	-	6.6
Mar 31	4.5	4.5	4.6	4.8	5.2	5.7	6.0	6.3	6.5	6.6	6.8	-	6.9
Apr 5	4.7	4.8	4.9	5.3	5.9	6.2	6.5	6.6	6.7	6.8	6.8	-	6.9
Apr 16	4.4	-	4.7	5.1	6.0	6.2	6.4	6.5	6.7	6.8	6.9	7.0	7.0
May 8	4.0	-	-	-	4.4	4.7	5.3	5.9	6.2	6.6	6.8	7.0	7.1
May 9	4.1	-	4.2	4.4	4.6	5.2	5.8	6.2	6.5	6.7	6.9	7.0	7.1
May 19	-	-	-	-	-	-	5.0	5.8	6.3	6.6	6.9	7.0	7.2
Jul 15	4.3	-	4.5	-	-	6.2	6.5	6.6	6.8	7.0	7.1	7.2	7.4
Aug 9	3.7	-	3.8	3.9	4.0	4.2	4.5	5.4	6.1	6.5	6.9	-	7.4
1981													
Jan 7	5.2	5.4	5.6	5.9	6.1	6.2	6.3	6.4	6.4	6.4	6.5	6.5	6.5
Mar 20	4.5	4.6	4.9	5.6	6.0	6.4	6.6	6.7	6.8	6.9	7.0	7.0	7.1
Jul 3	4.0	4.1	4.2	4.4	4.7	5.6	6.1	6.4	6.7	7.0	7.2	7.4	7.6
	0	5	10	20	30	40	50	60	70	80	90	95	100
	Percent of lake water												

TABLE D-5(for FIG.13) pH values obtained by mixing different proportions of melted snow and lake water.

Date	Percent of melted snow												
1980	100	95	90	80	70	60	50	40	30	20	10	5	0
Jan 17	5.1	5.6	6.0	6.4	-	6.6	6.6	-	-	-	-	-	6.7
Jan 23	5.0	5.4	5.7	6.1	6.3	6.5	6.5	6.6	-	6.6	6.7	-	6.7
Feb 23	4.7	4.8	5.0	5.5	6.1	6.4	6.6	6.7	6.8	6.9	7.0	-	7.0
Feb 28	5.2	5.5	5.8	6.2	6.5	6.7	6.7	6.8	6.8	6.8	6.9	-	6.9
Mar 2	5.2	5.5	5.8	6.3	6.5	6.6	6.7	6.8	6.9	6.9	6.9	-	7.0
Mar 24	5.4	5.5	5.6	5.9	6.0	6.2	6.3	6.4	6.5	6.5	6.5	-	6.5
Dec 18	5.5	5.7	5.9	6.1	6.3	6.4	6.5	6.5	6.6	6.6	6.6	6.6	6.6
	0	5	10	20	30	40	50	60	70	80	90	95	100
	Percent of lake water												

POOR

QUALITY

ORIGINAL